ABSTRACT
This report proposes the fabrication, construction and implementation of a Biodigester generation system to provide holistic waste, energy and economic solutions for the village of Devikulam, with associated community latrine and community stove facilities. Possible solutions were examined against a set of criteria and a community based solution was devised which, if implemented, would fix many holes in the village’s infrastructure and provide for new opportunities.
ACKNOWLEDGEMENTS

The group wishes to thank the following people who provided help & support throughout the project:

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- Dr David Hastie, Pro-Engineer software tutor
- Glen Anderson and EWB, for the opportunity to participate in the project
- Dr David Dowling and fellow authors of the informative textbook *Engineering Your Future*
- J S Vinod and Vish Karthik from the University of Wollongong for their advice on cultural matters
- Other members of DT01 who provided their feedback on draft versions of the project
- John Dryden (National Technical Sales Manager, BlueScope Steel) for advice on material selection and lead times
- Robert Reid (Operations Technical Coordinator) and Dave Smith (Instruments Coordinator) for their advice on process safety and process safety controls
EXECUTIVE SUMMARY

The village of Devikulam, located in South-East India, is currently plagued with a plethora of infrastructural problems on account of the social-economic climate throughout rural India over the past century. The village currently receives a supply of power from a state owned power grid which is consistently disrupted daily for about 3-4 hours with 'brown outs'. This is a particular problem as electricity provides lighting, refrigeration for perishables, and power for Televisions, an important tool for communication of information in rural areas. The aim of this report is to provide a solution for a backup power supply to provide electrical energy during the duration of these 'brown outs' that is of no cost to the environment, community and is relatively easy to maintain.

The five main solutions the team considered were solar energy, wind power, hydroelectricity, biogeneration system or making no change to the current supply of electricity. The team ruled out both wind power and hydro electricity as there was not a consistent flow of either wind or water in the local topography. Solar was ruled out as a solution since the region suffers a monsoon season which provides cloud cover for an extended period of time making the solution only viable during the summer months. The team decided against proposing a “nil solution” as this problem needed to be addressed as per the design brief. The team considered the option of designing a bio-digestion system to be the most appropriate solution as it could provide electrical energy, clean burning natural gas for cooking stoves and provide an aspect of community solidarity. The system also has prospects in solving other current problems in the community such as waste management, satiation and amenities.

The system devised incorporates a biogeneration tank with attached desulfurising tank, connected to a power generator which links to the power network. The system is supplied through a community latrine building and an input flume into which the villagers supply animal waste, and supplies a community stove building where meals are cooked using gas-fired clean stoves. The system is entirely run and maintained by the community and, given the large amount of infrastructure supplied, can be made for a relatively low cost using local labour, local materials and prefabricated sections, which can be installed in a very short timeframe.

In addition to this, the proposal outlines ideas for ‘next steps’ after installation, manufacturing plans, a plan for testing, full costings and engineering drawings, and details of the all-important safety controls.
As first-year engineering students, approaching an open-ended engineering problem with little technical knowledge or project experience will always be a difficult undertaking. The team comprised Thomas Crossman (Materials Engineering), Peter Varcoe (Materials Engineering), Najdo Panovski (Materials Engineering), and Lani Guerreiro (Mechanical Engineering), all first-year engineering students at the University of Wollongong and cadets at BlueScope Steel in Port Kembla.

In creating this proposal, the greatest difficulties experienced have been the lack of technical knowledge and time to meet in person. All team members would most likely have a lot more experience with solving real-life engineering problems and working in teams than other challenge participants. The team hopes to use this experience as it continues to design a solution, and also utilise the increased access to email and proper meeting facilities from their place of employment. Although there is not a great variety among the degrees being studied, team members have worked (as part of the cadetship program) in varied areas including plant operations, logistics, quality and maintenance. It is hoped that this would give greater insight into problem solving methods and the way in which different stakeholders interact in any engineering situation. It should also be noted that at the first-year stage of the degree, most students have only studied relatively common and generic content, so the lack of variety among degrees should not have been a huge disadvantage.

The team’s roles remained fluid, and changed in order to fill needs in the completion of the report. However the roles and tasks completed were roughly as follows:

- Thom completed most of the detailed design, functional & design description, manufacturing plan and engineering drawings.
- Najdo completed the design criteria, technical review, testing plan and cost evaluation.
- Lani researched and evaluated potential design options and identified ‘next steps’. She also coordination the presentations associated with this proposal and fixed the report’s appendices and references.
- Peter completed the construction & implementation plan, contributed to the option evaluation, and evaluated social/cultural connections and safety controls. He also collated and edited the final report.

The team notes that the challenge of the project has given a refreshingly different and challenging angle to university studies. It would also be of benefit to note that the project could be improved if the challenge related more directly to first-year technical university subjects and if additional specific technical data were given.

Judging by the Innovation Reports, it would appear that most of the engineering challenges in Devikulam have already been considered by professional engineers. With this in mind, and considering the very high standards set by previous EWB reports which all students should strive to match, the challenge could be improved if students were given an entirely open-ended problem that had not been previously considered. This would allow the high quality solutions created by
students to be fully utilized, and give students the feeling that they were genuinely trying to solve a real-life engineering problem. Considering the low levels of experience of participants, it would also help if participants could visit, or be given detailed examples of, a real EWB development – even if this meant making the challenge ‘closer to home’.
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1. PROBLEM STATEMENT

1.1 PROBLEM SCOPE

The explicit problem being addressed is the regular occurrence of brown-outs in the village of Devikulam. As per EWB sources, the locals endure power outages on a daily basis, with the average brownout period being 3 to 4 hours. As a result of this, the villagers of Devikulam may often lose power during critical times of the day where electricity is required for an important task, and it otherwise leaves them with inadequate lighting.

In addition, the villagers currently burn biomass to use cooking equipment, which is detrimental to their health, not to mention energy inefficient. The client representing Devikulam also wishes to see this problem addressed along with the constant brownouts.

1.2 TECHNICAL REVIEW

Electricity can be considered one of the most influential technologies developed and harnessed in scientific history, and has become a staple of the modern, developed world. Electricity has also been a key component in the Information Revolution, allowing the development of devices capable of computing and holding large amounts of data.

It is often the case that the developing nations of the world that cannot procure a reliable and secure supply of electricity to its citizens are the nations which are slowest in embracing closer technological links with other nations of the world. It could subsequently be argued then that these nations are also slow in embracing globalisation, which the Information Age has fast delivered to the world. However, irrespective of globalisation and the idea of integration of world cultures, electricity is a resource with high utility, and one that has become a standard of measurement for quality of life in the modern world.

Tamil Nadu is one of few Indian states which produce surplus power, which it sells to the neighbouring states of Andra Pradesh and Karnataka (TEDA 2011). It boasts several large power plants, including a nuclear power plant at Kalpakkam, a thermal plant at Ennore, a lignite power plant at Neyveli, a natural gas power plant at Narimanam, and a number of hydroelectric power plants. There are also plans to construct a new nuclear power plant in Kudankulam, which plans to add 2GW to the Tamil Nadu grid, with the first 1GW reactor coming online in October 2011, and the second in June 2012 (NCIPL 2011). As of 2005, the total electrical capacity for the state stood at roughly 8.2GW, with wind energy providing 3.6GW of energy, around 40% of the states power requirements. As of 2009, the power capacity of Tamil Nadu had increased to 10.2GW, with wind power still providing roughly 40% of power at 4.27GW (Know India 2009).
In the village of Devikulam, all but two of the households are connected to the main power grid. Formerly, power was considered to be a sort of luxury in Devikulam. However, recently it has been regarded as a resource that the villagers are becoming dependent on. In saying this, the lifestyle of the villagers could go on unperturbed during a brownout, since the main uses of electricity in Devikulam are to provide lighting, power fans during the summer, and in some households is used to power television sets and refrigerators for perishable goods. Electricity could also be used by the locals to operate a grinder to process perishables such as rice, grain and wheat more efficiently, giving them time to do other village tasks.

As mentioned in the Problem Scope, brownouts are a common event, occurring on a daily basis, often lasting between 3 and 4 hours of the day, although there have been cases of brownouts lasting longer than 4 hours.

This problem is one that requires an effective and immediate solution; however, a solution does not need to be able to provide the power requirements of Devikulam indefinitely, since brownouts only last between 12% and 15% of the day, as opposed to lasting 6 hours or more daily. Plus, power outages may occur during times when the usage of electricity is either minimal or non-existent, such as the early hours of the morning. In saying this, it is not known exactly when brownouts occur during a 24 hour period in Devikulam.

Therefore, improving the power infrastructure and the generator which powers the main grid is not an effective solution, since this would be far too expensive. Additionally, it would not be wise to construct a small-scale power station nearby, since the villages electricity usage is too small to warrant such a device, plus it would not be economical to install a station for only 390 people. Therefore, the most viable candidate for a brownout solution is the construction of an appropriate and suitable power generator.

### 1.3 DESIGN REQUIREMENTS

For such a generator to be considered a successful solution, it must satisfy a number of criteria as per the client brief:

- Installation costs must be kept to a minimum.
- Proposed solution must be able to supply the entire community with power during a brownout.
- It must be able to provide power efficiently.
- Solution must be designed to minimise maintenance of all processes involved.
- It must not require the removal of any indigenous flora.
- It is preferred that the solution provide power by ecologically sustainable means.

The solution should also be able to provide power to operate alternative cooking equipment to the biomass systems currently used, since these are known to produce fumes which can cause
respiratory problems. In addition, the combustion of biomass is energy inefficient due to the incomplete combustion of carbon in biomass. This method of cooking food has been used by the villagers of Devikulam for generations, since it is not possible for them to cut down trees for firewood, and no other sources of heat have been provided to them.

Based on the key problem being addressed, the final design criteria and their respective impacts can be summed up as follows:

**Table 1.1** Detail of reasoning behind use of design criteria

<table>
<thead>
<tr>
<th>Design Criterion</th>
<th>Source of Criterion</th>
<th>Importance to Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal installation costs</td>
<td>Benefits of solution must not be outweighed by exorbitant installation costs</td>
<td>Minimal installation costs are beneficial as they often translate to easy installation, since complex designs often lead to high implementation costs</td>
</tr>
<tr>
<td>Ability to provide efficient and sustainable power</td>
<td>More efficient transformation of energy and reuse of existing resources will reduce running costs</td>
<td>Reduces running costs and promotes ecological sustainability</td>
</tr>
<tr>
<td>Ability to provide sufficient power for villages needs during brownouts</td>
<td>The generator must be able to match the villagers requirements</td>
<td>The generator must be able to supply the entire needs of the village, otherwise its construction will be pointless</td>
</tr>
<tr>
<td>Maintenance/upkeep must be minimised</td>
<td>The villagers will most likely not possess refined technical knowledge</td>
<td>The villagers must be able to maintain and run the system themselves, and be able to fix minor faults</td>
</tr>
</tbody>
</table>
2. DESIGN OPTIONS

This section details the design options considered and the means used to decide which option would be selected as the final solution. As well as the specific measurable criteria used in section 1, it was considered to be desirable that the solution was:

- Environmentally friendly, in that it has a small environmental footprint, especially keeping in mind the importance of the Pitchandikulam forest and Devikulam lake.
- Socially and culturally acceptable to the community, and simple enough for the locals to operate it without difficulty.
- Of low safety risk to operate with little to no impact on the ongoing health and safety of residents of the village of Devikulam.

To this end, each of the options was considered in terms of safety, environmental impacts, added value, cost-effectiveness, and social & cultural factors. A decision matrix was filled out as a final evaluation of potential solutions. Hydroelectricity was given only limited consideration, but is included in the decision matrix for completeness.

2.1 DETAIL OF DESIGN OPTIONS

2.1.1. Design Option 1: Solar

Solar power utilises the photovoltaic effect to create a potential difference across a semi-conductor junction. The photovoltaic effect involves the displacement of electrons excited by medium-to-high frequency electromagnetic waves from a metal/semi-conductor with a relatively low threshold frequency. The number of electrons emitted is determined by the intensity of the light i.e. a more intense light source will induce a greater current in the circuit. The frequency of the light waves and the work function of the material directly determine the resultant kinetic energy that can be attained for each electron i.e. a HF (High Frequency) light source will give the free electrons a greater resultant voltage. Since electrical power is directly proportional to both current and voltage we need to have a light source that fulfils both criteria.

With current technologies, photovoltaic cells only achieve about a 10% energy conversion i.e. only 10% of the light that hits the cell excites an electron. Thus it requires a large area of photovoltaic cells to achieve the desired power output that would be required to run the village. For solar power to be a viable and reliable solution we are left with two main options:

1. Each individual appliance has its own small solar cell to power/charge it directly during the day time. This avoid problems with maintaining a power grid for the solar panels even though they would be most likely be backed-up onto the main grid during a 'brown out'. Additional problems with having a power grid, for the solar cells, is that they output with a direct current which has a slightly higher potential for electrocution than an alternating current has. The dangerous nature of DC can be coupled with the fact that there are known problems in India for power 'stealing', where residents simply jack their household supply
to a power line ad-hoc. This practice results in many fatalities in India each year. Thus reducing the need for a grid is desirable. Installing small solar panels on DC devices with a low draw such as street lights etc would be the most practical option for solar power. However a large, single solar array would need to be erected that would be run through an inverter for all of the appliances that run on AC during the day time.

2. The second option would be for have a single large array of solar panels for all of the villages' power needs. The number of solar panels would be determined by the bass current draw of the village. The electricity produced by the array would charge an array of batteries throughout the day. The batteries would be connected to an inverter and then to the grid. The array of batteries would be designed as to satisfy the power needs of the village for duration of about 3-4 hours (the length of a common 'brown out'). Having the array of batteries would allow the system to be more robust, especially on cloudy days and when ‘brown outs’ occur at a time where there is no sufficient light source to excite the solar panels.

Solar powered systems have a dependency on the availability of the Sun. This particular area of India has a monsoon season where cloud cover may last for several weeks. The monsoon system would last for several months, compromising the system’s reliability for this period of the year. A synergy between solar cells and another form of power generation is a prospective solution to the energy problem of the village.

2.1.2. Design Option 2: Hydro-Electricity

Hydroelectricity involves the conversion of the kinetic energy of flowing water into electrical energy. This is generally done by first giving the water a high potential energy, for example building up the water level by damming a river, and then allowing the water to run down to the bottom of the dam via a turbine. The high flow rate of the water spins the large turbine which turns a crank shaft attached to an electromagnet which induces a current in three surrounding solenoids by creating an oscillating electromagnetic field the a grid. In the case of Devikulam, any possible hydroelectric power generation mechanism would utilise the flow of the nearby lagoon. One idea would to for the flow of the river to power a mechanism directly using kinetic energy rather than electrical energy like an old wheat mill.

The hydroelectric option was quickly ruled out, as the flow rate of water depends on the acceleration due to gravity, which requires a vertical potential difference – a difference in height between the start and finish of the watercourse. In this case, the close proximity of the watercourse to the ocean means that there is very little change in height. Consequently, even if damming was used (which itself would have quite a catastrophic environmental impact on the surrounds), the flow rate would be too small to create a proper hydroelectric system.
2.1.3. Design Option 3: Wind Power

This form of renewable energy operates on the basis that the kinetic (moving) energy in the wind transfers its force onto the blades of the wind turbine, forcing the blades to rotate. This rotation then transfers along the central shaft and into a generator which, in turn, transforms this kinetic energy into electricity.

The average wind speed in Devikulam is approximately 5.4m/s, which would produce approximately 38kWh per month (Energy Matters 2011). This approximation is based on a turbine operating at its maximum 60 percent efficiency. In order to facilitate wind turbines in acting as reliable power source the village would need to be supplied with large, commercial turbines which would need to be purchased in decent quantity. The average cost of a fully installed commercial wind turbine is around $35 million. If the option were considered to install a smaller wind turbine which could only efficiently supply energy to one household, the reduced price of $35,000 - $50,000 would have to be considered.

2.1.4. Design Option 4: Bio-Digestion System (Biogas)

A bio-digestion system utilises the by-product gases, namely methane, of the anaerobic breakdown of organic material and burns them off to boil steam and produce electricity, or to directly fire gas stoves etc. the digestion process goes as follows:

**Figure 2.2 Flow chart of anaerobic digestion process**
2.1.5. Design Option 5: No backup power system

The option to not implement a backup power source and allow the Devikulam community to tolerate this issue was also considered. This option has been decided against as it is a problem which can be rectified with a simple engineering solution and could greatly benefit the community by offering a way of life which they deserve. If this issue was ignored the people of Devikulam would likely not be educated enough to solve the issue themselves as technology is constantly improving and they would be unaware of new technology and its complexities. The people of Devikulam are likely to not realise the opportunities renewable energy sources provide, understand its operation, benefits, or even how to install varying renewable energy technologies.

2.2 HEALTH & SAFETY

Safety should always be the first and primary consideration when evaluating any engineering problem. If the solution cannot operate without risks to safety being minimal, then it should not operate. When evaluating safety, the following principles were followed:

- The solution should theoretically be able to operate without any person sustaining harm.
- Even if changing the way a solution runs to improve safety means compromising its functionality, the potential solution is to be henceforth considered in its safe state.

Safety risks are to be considered in both their likelihood and impact of occurrence, on a scale of 1-5 for each. The sum of those constitutes the total severity of the safety risk. The lower the score the better.

![Safety Score Evaluation](image)

Figure 2.2 Safety score evaluation

2.2.1. Safety Considerations: Wind Option

Wind farms, by and large, can be seen to be a particularly safe solution. Were a large-scale wind turbine to be considered for Devikulam, the only real safety hazards would be regarding the structural integrity of the tower and common electrical hazards associated with the use of individual generators. If micro wind-turbines were to be used, which could also be a practical solution given the variable electricity requirements of houses in the village, the only additional hazards would be the position and structural integrity of the turbine and the use of additional
electrical equipment associated with 'off-the-grid' power. The use of appropriate circuit-breakers and switches (a extra but absolutely necessary cost) serves to minimise electrical hazards, and correct height restrictions and correct positioning for the turbines would minimise safety risks. Wind turbines have been said to create low-frequency sound which is detrimental to the health of those living near them. No conclusive body of research has backed this observation up, but it would be unwise for health reasons to locate a prospective wind turbine too close to the village.

Wind power was given a safety score of 3 (likelihood: 2, impact: 1).

2.2.2. Safety Considerations: Solar Option

Solar can also be regarded as a reasonably safe option. The hazards, as with wind, lie in the structural integrity of the mounting of the solar panels, and the use of 'off-the-grid' power if was the method used. The main additional hazard lies in the fact that an active array of solar cells becomes very dangerous in the case of fire or natural disaster. The solar cells would also be ordinarily mounted on a roof, but due to the high weight of relatively inexpensive solar cells and the low structural integrity of houses in the village this would not be the safest option. Due to these factors, the solar panel or array of panels would need to be located on ground level and given restricted access.

Solar power was given a safety score of 4 (likelihood: 2, impact: 2).

2.2.3. Safety Considerations: Biodigestion Option

The major consideration with the use of biodigesters and gas systems is the use of the gas itself as a power source. Biogas typically contains around 60% methane and 30% carbon dioxide, with no oxygen present. This makes it quite toxic if present in the air even in quite low concentrations, and extremely combustible. Depending on the number of steps in the process, gas may be present during the process which has highly elevated levels of carbon dioxide, methane, and nitrogen. Due to the anaerobic nature of the biodigestion process, the digester is necessarily sealed to prevent gas escape; however if so-called landfill gas does escape, it poses great risks to human health and safety. Gas storage systems are typically located on top of the biodigester in the form of a tank, equipped with an emergency purging burner and lightning protection rods. Purging systems, protection systems and valves would have to be sophisticated, well controlled and in good working order at all times to ensure the safety of this system, as the impact of a gas leak or gas accident is very high. The main biodigester would also have to be located well away from the village.

Biogas was given a safety score of 6 (likelihood: 1, impact: 5).

2.3 ENVIRONMENT

Related to safety, environmental considerations, both global and local, are the first of secondary considerations.

2.3.1. Environmental Considerations: Wind Option
Wind towers have almost no environmental impact in their methods of producing electricity, being powered by the natural forces of the wind. Large-scale wind turbines could be seen by the community to have a negative environmental impact, as they are obtrusive and require cleared land. In the case of the village of Devikulam, the land surrounding the village is either valuable farmland, valuable forest, or in close proximity to the lake. This means that a large turbine would be detrimental to its immediate environment. There are conflicting views over whether wind towers in general interfere with bird populations. The manufacturing process of wind towers involves the hot rolling of steel into plate, which is then roll formed into the curved shells required for the body and arms of the turbine. Although the manufacture of steel creates carbon emissions, this is a ‘once only’ as the material is 100% recyclable – making the manufacture more emissions-friendly than that of solar panels.

2.3.2. Environmental Considerations: Solar Option

Considerations for solar panels bear many similarities to those for wind. As per the safety evaluations, solar panels would have to be located on ground level, necessitating the provision of otherwise environmentally valuable land. However, solar panels are much less obtrusive. The manufacture of solar cells requires the conversion of silicon dioxide (mostly from sands) to silicon, a highly energy-intensive process which also requires mining of the silicon dioxide. As with wind, there are no environmental impacts to ongoing electricity generation.

2.3.3. Environmental Considerations: Biodigestion Option

A biogas leak would not only impact on the health of the community, but also on the health of any water systems and soil if it were to leak into these. The solid product (digestate) from the biodigestion process depends on the exact process. It is usually a stable cellulose-based material with traces of minerals and can be used as a home compost, which could benefit the people of the village. The liquid digestate can contain elevated levels of nutrients and is usually suitable for use as fertiliser. Another environmental concern is the discharge of wastewater with elevated biochemical oxygen demand, meaning that it would be unable to be discharged into waterways without further treatment.

Although it would seem that biogas contributes to global warming by causing emissions of greenhouse gases through the burning of methane, the primary component of biogas, this is not the case as biogas is simply gas that would have been emitted anyway and is captured. Normal decomposition causes carbon dioxide to form, as does the burning of biogas in air (oxygen). Therefore, biodigestion is functionally carbon-neutral.

2.4 ECONOMIC CONSIDERATIONS

The economic considerations surrounding implementation were already stated in section 1. The cost of a single wind turbine, being found to be $35-50m, was seen to be a prohibitive capital outlay for such a small village. Thus, only the option of single household wind installations was considered for evaluation.

These results can be summarised as follows:
Table 2.1: Overhead cost of installation vs power output

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Implementation costs per unit (est.) ($)</th>
<th>Electricity produced month (est.) (kWh)</th>
<th>kWh per dollar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>35000</td>
<td>38</td>
<td>0.0011</td>
</tr>
<tr>
<td>Solar</td>
<td>2500</td>
<td>192</td>
<td>0.0768</td>
</tr>
<tr>
<td>Biogas</td>
<td>23000</td>
<td>3200</td>
<td>0.1391</td>
</tr>
</tbody>
</table>

2.5 LONG-TERM VALUE ADDITIONS

2.5.1. Wind & Solar Options

The wind option, although subject to very high installation costs, has very little maintenance and has little ongoing impact upon the community. The same is true for solar panels, which has lower installation costs. However, the value of these options is compromised by the fact that they gain their energy by variable means. Wind is not always available, and solar is never available at night. As has been previously noted, Devikulam suffers from blackouts and brownouts, and is in need of a backup power supply. The use of variable supply would only increase this need. If solar or wind were to be used for mains power, they would require a large backup fuel cell to be installed to hold power for discharge at peak times or where there would otherwise have been power outages. If solar or wind were to be used for powering individual houses, buildings, or lights, the systems would need integrated batteries, which would drive up costs further.

2.5.2. Biodigester Option

The biodigester option adds a great deal of value to the community in that it also helps to solve the community’s waste problem and provides a source of fertiliser. Owing to the technical management of the gas systems and the larger size of the facility, the biodigester would require more maintenance than other alternatives. However, if it provided cheaper power every month, this would offset or outweigh the maintenance cost. The gas power system (using the biogas) also incorporates a storage facility and a constant supply of gas, meaning that there is no need for a backup power system.

2.6 SOCIAL & CULTURAL

2.6.1. Wind & Solar Options

Wind turbines and solar panels would most likely be accepted by the community if they were for personal use rather than a large tower or solar array. Such large installations would be obtrusive, take up otherwise valuable space, and be in stark contrast to the otherwise rural surrounds.
Personal solar and wind power would be more acceptable as it would be less obtrusive and also give people a sense of independence and responsibility. However, both of these solutions require additional spending to solve the major social objective – elimination of brownouts and blackouts. Both wind and solar offer opportunities for local people to be involved in the fabrication and installation of such solutions, and to be trained in the maintenance of individual electrical systems.

2.6.2. Biodigester Option

The biodigester would have a large social impact due to its adding of value to the agricultural industry, the economic base of the Devikulam area. It would also help to solve waste problems and to improve general hygiene. If gas was connected to every house, this would solve heating and cooking problems, something for which houses already use kerosene. Adjusting to the use of a sophisticated system would be a challenge, but local people could be trained in the necessary systems, inspections, instrument fitting, electrical knowledge and gas safety. The only significant risk to the community is the unlikely scenario of a gas leak into soil or water, especially the Devikulam lake, or that the lake developed algal blooms as a result of wastewater being leaked into it. Any impact on the lake would discourage tourists to the ‘holy lake’, another important part of the local economy.

2.7 DECISION MATRIX

Each of the four options (Do nothing ruled out in initial considerations, as per Section 2.1) was given a score based on how it fulfilled each of the criteria. Each score was out of ten, with lower scores being better.

Table 2.2: Decision Matrix for potential solutions

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Wind</th>
<th>Solar</th>
<th>Biogas</th>
<th>Hydroelectricity</th>
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<tbody>
<tr>
<td>Safety</td>
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<td>4</td>
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<tr>
<td>Environment</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Economic</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Added Value</td>
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<td>4</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Social &amp; Cultural</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>20</td>
<td>18</td>
<td>34</td>
</tr>
</tbody>
</table>

2.8 OPTION SELECTION

As a result of a wide scope of information, knowledge and intellect amongst the team members, coupled with extensive research, it was relatively easy for the team to decide on the course of
action for the backup power supply dilemma. The team chose to pursue the bio-digestion option due to a number of advantages this option holds over the other more generic solutions:

1. Using a bio-digestion system allows for a strong aspect of community involvement whereas other solutions, such as solar, require technical expertise to setup and maintain the system. Having a strong community involvement behind the solution is crucial to maintaining its longevity and security.
2. There is potential to fix other community problems in the village through this system such as waste management and sewage treatment. This is because most of the villages waste output is either human, animal born or household waste which is all biodegradable, therefore can all be an input stock into the digestion system.
3. From a design perspective this solution allows for the greatest creative freedoms in the design process.
4. From a cost perspective, the bio-digester is easily the most competitive.
5. The biogas produced can power both an electrical generator and natural gas stoves, providing a potential to solving the health problems faced by the villagers who still currently use biomass fuels for cooking.

There are also numerous reasons why a bio-waste digestion system is the most appropriate solution specifically for Devikulam village:

1. The village has a vast supply of waste (this is noted in another facet of the EWB challenge) such as cow manure, human sewage and food waste.
2. The methane gas is a relatively clean burning product and it can be used to power the gas stoves in the households as well as be burned to provide electrical energy.
3. Numerous systems within the villages can be integrated into the bio-digesters such as adding a communal toilet which septicly treats the sewage.

Let it be noted that a bio-digestion system allows for an aspect of community involvement, with systems/programs that aim to collect organic wastes throughout the village such and animal manure, sewage and household waste.
3. DESIGN DESCRIPTION

3.1 SUMMARY OF DESIGN

The nominated bio-digestion tank design is aimed at satisfying a number of design aims. These are:

- To provide a suitable back-up power supply solution that is cheap, easy to use and has little or no impact to the environment or general health and safety of the community of Devikulam.
- Provide a solution to the problem of biomass stoves by either redesigning their stoves or finding an alternative fuel source.
- Implement a strategy to process the large output of household waste in Devikulam in order to improve sanitation conditions.
- Create an infrastructure for sewage treatment.

There are various facets to the design which allow for each of these goals to be comfortably met. All of these components come together to register a very simplistic, cheap and easy to build design. Since the village has very little technical experience among the villagers or in the local area, the tank is specifically designed to have minimal moving parts to allow for easy maintenance and a lasting construction.

The bio-digestion system is essentially a tank comprised of three pre-built modules and two pre-build annexes. The three modules form the shell of the tank which has two flumes attached to it: an input and an output. The input flume is for the incoming bio-waste the villagers have collected and the output flume acts as a form of overflow for the tank.

To make the design as robust as possible and to maximise the gas yield, a decision was made to make the input chute unique by connecting it directly to five overhead communal toilets where the sewage will go directly into the tank. This not only solves the problem of providing a large enough bio-waste input to satisfy energy needs, but also of the untreated sewage dilemma within the village. The input waste from this flume would be general household waste such as food scraps as well as animal waste such as manure.

The input materials will be mixed with a large portion of water initially when the tank is first commissioned. The water will help create sludge for the bacteria to flourish in. Also, since water is a non-compressible liquid, it will create a seal to stop gas from being released up into the input chute as well as allowing the gas in the tank to pressurise.

From when the bio-waste is first put into the tank, it will take about 2-4 weeks for the bacteria to start producing methane [under the right conditions]. The tank is designed for a continuous process; thus, once the methane starts to be produced by the bacteria, it will keep being produced at a constant rate that is directly proportional to the input of waste. The tank will also be placed
underground, apart from a small section of the top module. This will keep the tank at a relatively constant operating temperature between 30-60 degrees, which is a desirable temperature for the survival of the bacteria.

The gases produced, largely methane, will travel through the desulfuriser where the H₂S (which causes problems during generation and distribution) will be removed. From there they rise to the top of the storage tank since they are less dense than air. As more gas is produced over time, the gas will start to build up pressure. There will be three ball valves on the base of the storage tank: one will lead to the power generation unit and one will lead to a safety flare; the other will lead to a group of communal gas stoves about 100m away.

The communal gas stoves will be shared amongst the residents of Devikulam and be a great alternative to the current system of biomass stoves within household which pose a great health risk. Making the stoves a shared facility will reduce the amount of gas infrastructure needed, which will be a cost saving, as well as reducing the distance the gas has to travel.

The power generation unit will essentially be a gas generator with will be turned on in the event of a power outage. A ball-valve will be automatically turned open at the top of the storage tank to produce a flow of gas to the generator and then turned off when the state power supply has resumed, as controlled by a control computer. The generator will produce an AC which will be connected directly to the existing grid. This power supply should be sufficient to assuage the grievances of the villagers during these power outages, thus satisfying the aim of a backup power supply system.

The output flume, from the digester, runs off the excess sludge from the digester. The output sludge is not just waste, it can be a very useful material for irrigating crops (due to its large water component) and for fertilizing crops (nitrates and phosphates from manure). To make use of this great fertiliser, the output chute will run off into a vegetable patch using a basin flood method of irrigation.

There is a strong focus on the ease of construction in this solution as there is little or no skilled labour in Devikulam. Thus building each module off-site, shipping them in and then simply connecting each module together on-site saves on labour costs from importing workers, design costs, as well as creating a quality assurance.
3.2 DETAILED DESCRIPTION

The bio-digestion system is essentially a tank comprised of three pre-built modules and two pre-built annexes. These are:

- **Bottom module:** This is essentially the base of the tank and is where most of the biomass will rest. It is a large concave dish to allow for an even distribution of the biomass from the input flume. Along the outer circumference on the dish is a 150mm wide rim with four 15mm diameter holes. This rim essentially serves as a flange to bolt to a corresponding rim on the middle module of the tank.

- **Middle module:** The middle module is a cylinder a diameter of 2000mm with two 150mm rims at top and bottom lips. It has two oblong slots cut out of the wall of the cylinder, one of the input flume and the other for the corresponding output flume. The input flume is situated approximately 300mm higher than the hole for the output flume; this is so the input shoot does not fill up with waste, which would block in the incoming biomass, when there is an overflow in the tank.

- **Upper module:** The upper module is essentially the lid of the tank. It is very similar to the lower module except marginally taller. This increased height is to allow for more gas to be stored. This module is notably thicker than the other modules (5mm). This is because it is not completely under the cover of soil, thus the steel must be thicker in order to maintain the pressure of the gases to within a reasonable factor of safety.

The body of the biodigester is attached to a desulfurising tank. The gas flows from the top of the biodigester into the desulfurising tank and is further bacterially decomposed in order to remove sulfides which can erode the insides of pipes and generators, and reduce the cooking performance of the biogas. The cleaned biogas rises from the desulfuriser into a thick rubber gas storage unit, which expands to hold pressurised gas for easier flow. The gas flows from here to a flare for getting rid of excess gas, to the generator, and to the community stoves.
Figure 3.2.1 Community latrine

Figure 3.2.2 Biodigester tank
Figure 3.2.3 Desulphuriser & storage tanks

Figure 3.2.4 Community stoves & stove top
The following diagram shows how the biogas system parts and community interact to create a continuous, homogenous generation system.

**Figure 3.2.5 Biodigester process: conversion of waste into electricity**
3.2.2. Functional Description

Household Waste:

This counts for all bio-degradable waste that is produced in the household, excluding sewage. This generally covers waste such as food scraps and nothing more. The scraps will be collected by the household members and thrown into the input flume on the bio-digester.

Animal Waste:

The animal waste is a general term of the animal excrement. Manure is collected off the ground with a shovel and scooped into a wheelbarrow or a similar device. The wheelbarrow is then emptied into the input chute.

Sewage:

The sewage is any human excrement from any of the communal toilets placed adjacent to the tank.

Collection of materials:

This is the general process of the villagers gathering the bio-waste materials around the village on a daily basis and putting them into the input chute. It is vital that this is done regularly to the keep the production of gas at the optimal level.

Input of materials:

The bio-waste materials will be input into the tank via either one of two ducts. The first duct is the main flume which is connected to a small well at the surface. The well is the orifice where the household and animal waste a submitted. The second duct is connected to the main duct at its mid-section. The main duct is directly supplied from the community latrine, where the toilet bowls feed directly into a central pipe. The waste from the central pipe of the community latrine goes into the main duct thus into the tank.

Addition of water:

Water is added to the semi-solid waste to create sludge. Upon commission of the tank it should be filled up with water until it comes out of the overflow chute. Not only does having sludge provide a greater surface area for the bacteria and breakdown some of the waste, it also allows the waste to have a low enough viscosity to be extracted through the output chute and used to irrigate. An added note is that water is an incompressible liquid, which creates a seal in the tank to prevent gas from leaking out of the input flume and also to pressurise the methane gas at the top of the tank.

Biomass sludge:

The water and biomass components mixed together to create a sludge which provides a greater surface area for the bacteria to digest the waste, increasing the rate at which the gas is produced. Using the waste in sludge form also allows the output flume to work efficiently.
Excess sludge:

As waste is added to the system via the input flume, the total volume of sludge will remain the same as an output flume with run off any excess sludge at the same time. The excess sludge will be used to fertilise and irrigate a small vegetable garden, since the manure input contains high amounts of nitrates and phosphates.

Vegetable patch:

The vegetable patch will be adjacent to the bio-digester and directly take advantage of the nutrients from runoff from the output flume. The vegetables will be picked in season and eaten with the scraps going back into the digester via the input flume.

Production of methane:

Bacteria in the digester perform hydrolysis on the input materials breaking them down into insoluble organic polymers e.g. carbohydrates. Acidogenic bacteria break down the carbohydrates and subsequent amino acids to produce a range of organic acids and off gases such as hydrogen, ammonia and carbon dioxide. Acetogenic bacteria convert the organic acids into acetic acid. Methanogens convert the acetic acid into methane and carbon dioxide. The methane is collected at the top of the system and tapped off to power a generator and communal gas stoves.

Gas collection:

As methane is lighter than the sludge it will build up at the top of the tank. As the water is incompressible the more methane that is produced the greater the pressure in the tank. When the pressure is great enough due to build-up of gas in the desulfuriser, main tank and storage, the gas is tapped off to go to either the power generator or the communal stoves.

Biogas tapped for communal stoves:

At the top of the tank there are two ball-valves; one will lead to the power generation unit, the other to a set of communal gas stoves. The desulfurised gas will fuel these stoves directly. The stoves will be relatively close to the tank, roughly 50-100m, as to reduce costs of a gas-line infrastructure.

Gas tapped for power generation:

No more than 50-100m from the bio-digestion tank will there be a gas electrical generation unit. The unit will be wired directly to the state owned power grid and will be turned on in the event of a power outage. The electricity produced will be an AC.

Power generation:

The gas generator is an internal combustion engine that drives an AC alternator. The combustion of gas is exothermic. The heat produced from this reaction expands the gases within the cylinder pushing a piston downward. The piston is attached to a crankshaft with other pistons at different stages in the cycle. The crankshaft drives the electromagnet of the alternator. As the electromagnet spins it produces an oscillating electromagnetic field which induces a potential difference in the
three solenoids positioned at 120 degrees apart in the generator. The electricity produced is then wired to the grid.

Generator connection to grid:

The generator is simply connected to the grid via a switch which when loses power automatically turns the generator on. The generator produced electricity and it flows back through this junction into the state owned grid. When the switch regains power from the state electricity, the generator is turned off. The grid is connected to all but two houses in Devikulam. The electricity is used to power lighting, fridges and televisions.

Use of power in village:

Lighting and televisions are the main consumers of electricity in the village. Television is an important device in India for communicating various messages such as the news. Three households in the Devikulam power fridges to preserves perishables such as food. There is also a rice flour grinder in the villages which uses electricity. This grinder does a task which can take days if done manually.

3.2.3. Tank Design

The three modules of the tank are assembled using a series of six 8R stainless steel threaded rods which extend the whole length of the middle module (1100mm). These rods take a tensile loading due to compressing the modules and gaskets together by tightening nuts at each of the threaded rods. The whole construction of the tank is made from stainless steel to avoid any areas of the tank having a potential difference.

3.2.3.1. Lower Module

This is essentially the base of the tank and is where most of the biomass will rest. It is a large concave, stainless steel dish to allow for an even distribution of the biomass from the input flume. Along the outer circumference on the dish is a 5mmx150mm stainless steel rim with four 16mm diameter holes. The inner circumference of the rim is 2300mm and the outer circumference is 2500mm. This rim essentially serves as a flange to bolt to a corresponding rim on the middle module of the tank. The rim would be welded to the dish by a boiler maker in the fabrication workshop before it was shipped to India. The wall of the dish is only 5mm thick, this is all that is needed to the shell being compressed by the surrounding soil thus any pressure exerted by the gas would be equalled by the reaction force of the soil. The lower module is bolted onto the flange on both the middle and top modules using bolts and threaded rods.

3.2.3.2. Middle Module

The middle module is a cylinder a diameter of 2000mm with two 150mm rims at top and bottom lips. It has two oblong slots cut out of the wall of the cylinder, one for the input flume and the other for the corresponding output flume. The input flume is situated approximately 300mm higher than
the hole for the output flume; this is so the input chute does not fill up with waste, which would block in the incoming biomass, when there is an overflow in the tank.

3.2.3.3. Upper Module

The upper module is essentially the lid of the tank and is where the gas will be stored before being transferred to the desulfurising tank. It is very similar to the lower module except marginally taller. This increased height is to increase the amount of recently fermented gas that can be stored and the area in which fermentation occurs. This module is also notably thicker than the other modules (5mm). This is because it is not completely under the cover of soil, thus the steel must be thicker in order to maintain the pressure of the gases to within a reasonable factor of safety.

3.2.3.4. Input Flume

The input flume caters for the income of waste directly from both the chute and the communal toilet and redistributes this input into the tank. The input flume consists of two main conduits: One for waste manual dumped into the flume at the surface, and another that runs directly from the sump of the communal toilet. The input chute carries a dimension of 500x500x500 mm, large enough to cater for a wheelbarrow of waste at a time. A small grid will be placed in the chute at ground level to prevent any persons from falling into the tank. The second conduit for the communal toilet is much smaller than the ground level chute at 150x300x500 mm. This is enough to cater for a daily purge of the communal toilet sump. At the end of the input flume the there is a curved flange that is shaped to fit the exterior of the tank. This flange is design for attaching the flume to the tank, where the flange will be pop-riveted to the outside of the tank at the specified location on the middle module. The top of the flume (where it meets the tank) must be lower than the top of the output flume drain, in order to maintain the water level above the orifice for the input waste. This will ensure none of the product gas will seep out through the menisci of the waste and the top of the flume. Ensuring this design constraint is met will vastly increase the total gas security of the tank.

3.2.3.5. Output Flume

The output flume is designed specifically to ensure the bio-gas production is a continuous process. As input waste/slurry is added to tank, a small portion of waste will also leave the tank via the output flume. Compared to the input flume, the output flume is much smaller. Like the rest of the components of the tanks the output flume is fabricated from stainless steel. The top of the output flume must be above the top of the input flume in order for the water level to always be above the input flume. The output flume feeds directly into a 3000mm long piece of UV resistant PVC pipe and into a small vegetable patch. The output waste will be high in phosphates and nitrates from the manure, thus, it acts as very good fertiliser for a small plantation. The high water content of the output waste will accumulate to form a type of basin irrigation. The bottom of the output flume sits 100mm above the bottom of the Middle Module. The cross-sectional area of the output flume is less than that of the input flume. This is because clogging of the outgoing waste is not as important of the incoming waste.
3.2.4. Desulfuriser & Storage

The desulfuriser is where the gas is cleaned before being sent out for use. The construction is almost identical to a standalone version of the middle module of the main tank, except each end is sealed. The gas flows into the lower end of the desulfuriser from the top module of the biodigester where the bacteria begin to remove the sulfur compounds. The gas flows from the top of the desulfuriser directly into the storage module. The harmful small amounts of sulfur are removed from the bottom of the tank through a pipe on the opposite side to gas delivery and go into an accessible hollow pit, from which the sulfur is removed during routine tank maintenance.

3.2.5. Auxiliary Infrastructure Design

3.2.5.1. Communal Toilet

For a bio-digestion system human faeces are a nutrient rich feed stock. Utilising this almost unlimited resource for the benefit of community can only be met with good intentions. The community already suffers from the problem of open defecation; thus, having providing a communal toilet to both solve this problem and provide a huge input into the community’s power supply makes this a valued feature of the design. The toilet is designed to rig directly onto the input flume and can accommodate up to eight community members at a time. The base of the toilet is 2000 mm wide and takes the shape of an octagonal prism. For simple construction there are four dividers which each span the diameter of the base. The dividers have a longitudinal slide in the middle where each divider stacks on top of the other to form a rigid structure. In each divider there are four small angled slots. These slots are for sliding in the cistern backboard for each cubicle. Once each back board is slotted in, the cistern of the tank has been formed. The cistern of the tank will hold enough water for the toilet contents of the toilet sump to be purged at least once a day. The cistern will be filled up with water from a nearby bore well and also from rainwater, as the toilet roof is slanted with an orifice to capture rainwater. The ‘flush’ mechanism is in the form of a long rod with two stoppers attached to it. The lower stopper plugs the sump of the toilet, and the upper stopper plugs the cistern. When the rod is lifted, the cistern will empty into the sump and the sump will empty into the input flume. The water from the cistern will help flush all of the contents from the sump into the flume, as well as provide a large water component to the bio-waste sludge.

3.2.5.2. Gas Infrastructure

Choosing to have a shared community house for the bio-gas stoves greatly saves on the infrastructure costs of having gas piped to each individual homestead. The gas pipeline will run from the bio-digestion tank to the desulfuriser tank. The gas will run along two separate lines from the desulfuriser tank: one to the community cook house; and the other to the power generation unit. The gas will be controlled by a series of ball-values at each critical point along the pipeline. The pipe used will be 8R stainless steel pipe.
3.2.5.3. Power Generation Unit

The gas power generation unit is a General Motors Kohler 45REZG. It has a peak power output of 53 kW, more than enough to accommodate for the community during the common blackouts. The generator will be directly connected to the grid and will automatically switch on when the State feed ceases.

3.2.5.4. Communal Cook House

To save on the cost of having a gas infrastructure spanning the village, the team decided to localise the costs and only have one building which the pipeline ran to for cooking. This building would house 24 stoves and be made up of 3 modules.
3.3 MANUFACTURING PLAN & BILL OF MATERIALS

The manufacturing plan & bill of materials uses the full bill of components for the tank, as described in the design description & functional description, and provides a succinct graphical plan for fabrication. All component drawings are found in Appendix 5.

3.3.1. Biodigester

Table 3.3.1: Biodigester Components Provided

<table>
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<th>Component No#</th>
<th>Component</th>
<th>No# of Components</th>
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</tr>
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<td>1</td>
<td>Lower Module</td>
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<tr>
<td>2</td>
<td>Threaded Rod (1100x8R mm)</td>
<td>9</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>Middle Module</td>
<td>2</td>
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</tr>
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<td>4</td>
<td>Gasket</td>
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<td>5</td>
<td>Upper Module</td>
<td>1</td>
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</tr>
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<td>6</td>
<td>Output Flume</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>Input Flume</td>
<td>1</td>
<td>26</td>
</tr>
</tbody>
</table>

Step 1: Place Lower Module in 2000mm deep hole

Step 2: Place 6 Threaded Rods w/Nut attached through 8 of the holes on the Lower Module and ensure the 2 remaining holes are opposite.
Step 3: Place Middle and Upper Modules on the Lower Module guided by the Threaded Rods, with a gasket in between each module.

Step 5: Use Pop-Rivets to attach the flange of the output flume to the side of the Middle Module.
Final Step: Use Pop-Rivets to attach the flange of the inner flume to the side of the Middle Module.
Table 3.3.2: Toilet Components Supplied

<table>
<thead>
<tr>
<th>Component No#</th>
<th>Component</th>
<th>No# of Components</th>
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<tbody>
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<td>1</td>
<td>Base Skirt</td>
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</tr>
<tr>
<td>2</td>
<td>Sump</td>
<td>1</td>
<td>09</td>
</tr>
<tr>
<td>3</td>
<td>Base Top (Seat)</td>
<td>1</td>
<td>02</td>
</tr>
<tr>
<td>4</td>
<td>Divider (Lower)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Divider (Lower-Middle)</td>
<td>1</td>
<td>03</td>
</tr>
<tr>
<td>6</td>
<td>Divider (Upper-Middle)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Divider (Upper)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Cistern Backboard</td>
<td>8</td>
<td>07</td>
</tr>
<tr>
<td>9</td>
<td>Roof</td>
<td>1</td>
<td>08</td>
</tr>
</tbody>
</table>

Step 1: Place Base Skirt Board on ground above inner flume plumbing infrastructure.
Step 2: Place toilet Sump in the Base Skirt Board.

Step 3: Secure Toilet Seat onto the base with screws
Step 4: Slot all of the dividers, in succession, onto the base top.

Step 5: Slide all 8 backboards into position to form the cistern of the toilet.
Final Step: Secure roof to onto of the dividers and screw in place doors.

*Figure 3.3.2 Toilet manufacturing plan*
3.3.3. Community Stoves

**Step 1: Layout louver panel**

**Step 2: Slide hanger clamps onto narrow faces of the panel and bolt on to secure.**
Step 3: Place stove tops onto bench assembly and connect to gas.

Step 4: Place bench assembly into middle module and connect to gas.
Step 5: Place bench assembly in each of the side modules.

Step 6: Place louver assemblies in rack with 120mm between one another.
Step 7: Place upper rack on louver hangers to secure assembly.
Step 8: Place louver assemblies into nominated windows slots on both side.
Step 9: Connect each module to the corresponding side of the middle module.
Figure 3.3.3: Stoves manufacturing plan

Table 3.3.3: Stoves Components Supplied

<table>
<thead>
<tr>
<th>Component No#</th>
<th>No# of Components</th>
<th>Component Name</th>
<th>Drawing # (Appx. 5)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>132</td>
<td>Louver Panel</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>264</td>
<td>Louver Hanger</td>
<td>47</td>
</tr>
<tr>
<td>3</td>
<td>264</td>
<td>Louver Hanger Bolt/Nut</td>
<td>48/49</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>Stove Top</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>Bench</td>
<td>41</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Side Module</td>
<td>44</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Centre Module</td>
<td>43</td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>Louver Rack</td>
<td>45</td>
</tr>
</tbody>
</table>
4. SYSTEM CREATION & IMPLEMENTATION

Given that the biodigester is a machine requiring manufacturing, a facility requiring construction, and a process requiring implementation, the design is supported by a manufacturing, construction and implementation plan.

4.1 FACILITY CONSTRUCTION PLAN

The biodigester does not function as an independent unit – it relies on several other constructions in order to give it material and handle its output. There are three main facilities associated with the biodigestion energy system:

- The community latrine.
- The Biodigester tank and generator, using the biogas to generate electricity.
- The community gas cooking stoves.

4.1.1. Community Latrine

The community latrine presents a significant hurdle in design due to the nature of the community’s views on it. The Innovation Report recommends against their use, stating that:

“While commonly provided dry or compost toilets have significant benefits associated with not requiring water and allowing for simple and safe waste disposal, they have been implemented in rural villages with varying rates of success largely as a result of social issues. It is suggested that if they are to be implemented, significant educational support would be required. In addition, the provision of biogas systems would also require significant support as the use of human waste as a fertilizer presents an issue with the local culture.”

Earlier, the report also states that:

“Initially the project team explored the possibility of implementing a common toilet for the village, however after some review of existing facilities and community consultation, it is expected there will be ongoing problems with maintenance (it is unlikely that anyone will take responsibility for cleaning the common toilet).”

The team believes that these problems can be overcome by integrating the system correctly with the community and designing the facility correctly. The building would consist of many independent toilet cubicles, each containing a single toilet which would belong to a single household. The household would then be responsible for maintaining this particular toilet. The toilets themselves would contain a flap (attached to a spring and hinge) which would allow the waste to exit the bottom of the toilet while concealing the waste.

The partitions for the cubicles would be made of wood. The building could be designed so that cubicles faced outwards onto a 1 m external corridor (still inside the walls).
Other possible variations in the construction of this building which could help to make it more socially acceptable include:

- The toilets could incorporate some kind of small flush with water from a tank mounted on the roof of the facility.
- The toilets could use a urinal which would then only feed into the digester tank, if it is deemed to be socially unacceptable to use solid human wastes in fertilization.
- The building could simply not be used at all if the entire part of the process is considered socially unacceptable after further education and support. The animal wastes and food wastes alone could be sufficient to fund the biodigester depending on its size and the amount of gas required.

4.1.2. Biodigester Tank & Generator

The biodigester and generator will be completely pre-fabricated and installed as fabricated, with the only changes being their connection to existing feed and gas infrastructure. The biodigester tank body is to be mounted sub-surface, so some earth works will be required to excavate a hole the size of the biodigester tank. If the toilet block is to be constructed above the biodigester, there will be no excavation required for waste pipe work; otherwise, a channel will be dug 1.5 metres below the surface to input the waste pipe(s) leading from the toilet block to the biodigester. The earth around the biodigester will be filled in and packed in to support the biodigester. The gas collection at the top of the biodigester will be piped above the surface to the generator, located between 50 and 100 metres away from the digester. The generator would be mounted in a small above-ground brick powerhouse with an adjacent small high-voltage yard containing transformers.

The biodigester would also supply gas to another set of underground pipes (for which trenches would also need to be dug) which would then go out to each of the community stove centres.

4.1.3. Community Stoves

The community stoves complex would be the second significant building for human use in the system. Unlike the toilets, there are fewer social issues with the stoves building. The stoves obviously do not have any relation to human waste, and do not require ‘ownership’ for cleaning purposes. The maintenance of the stoves would most likely be looked after by an individual or team in charge of looking after the biodigester and the rest of the gas systems.

The building would be prefabricated in 3x5 metre sections, the same dimensions as the community toilet block. The individual stove building sections would also contain the same framing as the toilet block. The walls would be made of vertical steel sections, which could be individually or collectively turned in and out like a set of vertical drapes, as per the climate and settings desired by the occupants. Within each 3x5 metre section, stoves and benches would occupy the central 3x1 metre area. Each household would have responsibility/rights to one particular stove (i.e. 1x1 area or smaller) on this bench. A central gas pipe would service these stoves. The 3x5 sections could be attached together to create an extensive building, depending on community response, demand, and
the settings of these stoves. One community stove centre could potentially be built in each of three main areas of the village (north, south-west and south-east).

4.2 IMPLEMENTATION PLAN

4.2.1. Implementation Timeline

The following timeline could be used to bring the project from scratch to ready-to-use:

<table>
<thead>
<tr>
<th>Weeks</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
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<tr>
<td>Materials Fabrication</td>
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<tr>
<td>Building Fabrication</td>
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<tr>
<td>Digester Fabrication</td>
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<td>Preliminary Earthworks</td>
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<td>Delivery of System</td>
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</tr>
<tr>
<td>Installation of System</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste collection begins</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 4.1 Timing of steps to complete building & installation of solution

4.2.2. Installation, Proceeding to Use

The community needs to be educated in the use of the biodigester as a matter of great importance, before it is considered ready to be put into the hands of the community. Any social issues relating to the use of human waste and community buildings need to be overcome through education of the villagers of the benefits of the biodigester, both to fixing cooking, sanitation and power supply issues in the short term, and enabling increased economic development in the long-term.

As well as this education, the community as a whole needs to be readied for the use of the system. Routines need to be established over the collection of manure, as well as the replanting of the vegetable garden. Households need to be educated in the provision of compost and why this is required for the biodigester. In addition, the village as a whole needs to be educated in the safety hazards associated with the biodigester and with biogas in general.

There are several specialist positions which will need to be created in order for villagers to take full ownership of maintaining and using the system. The first is an electrical specialist who is in charge of maintaining the generator systems and the logic for the backup power supply. The second is an instrument mechanical specialist who maintains the entire system of valves, fittings and
instruments which monitor gas levels. The final position is a system coordinator who monitors gas levels, takes ownership of gas safety emergency response and gas safety education, and handles interactions between the villagers and the system. Filling these positions by training local people would create jobs in the community and make sure that the system is fully owned and run by the people that use it.

4.3 SYSTEM DISCUSSION

4.3.1. Strengths and Weaknesses

Despite having chosen Biogas as the primary method by which to provide a reliable backup source to the village of Devikulam no solution is perfect. As with many things, there are pros and cons to this solution which must be considered when contemplating the introduction of this type of technology. Resolutions to the negative aspects of Biodigesters should also be considered where possible.

Table 4.2 Pros and cons of biodigester proposal

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
<th>Possible Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harnesses resources already available within the Devikulam community. i.e. animal faeces, organic materials.</td>
<td>Potentially dangerous. Chances for explosions to occur.</td>
<td>Educate the community to the dangers of Biodigesters and how to avoid such occurrences. In addition to this it should be ensured that the digester is installed properly and with extra safety precautions such as a lead free safety relief valve (hydrogen sulfide in biogas destroys lead, which will cause gas leaks). Also flame arresters should be placed in all gas lines as a precautionary measure.</td>
</tr>
<tr>
<td>Is a renewable and sustainable energy source.</td>
<td>Potential cause smell pollution if a leak occurs.</td>
<td>Install properly, educate on maintenance. Ensure the facility is installed properly, educate the villagers on how to check for leaks and maintain the Biodigester.</td>
</tr>
<tr>
<td>Is constantly producing therefore is a reliable source of power. Can be programmed to produce less at night or times when not as readily required for</td>
<td>High cost of installation and maintenance.</td>
<td>Through effective installation, premium energy output can be obtained which will assist in the facility paying for itself in the nearer future.</td>
</tr>
<tr>
<td><strong>maximum efficiency.</strong></td>
<td><strong>Economising – by products of process can be either used by the community or sold.</strong></td>
<td><strong>Economising – by products of process can be either used by the community or sold.</strong></td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Hidden additional costs - Need to purchase components separately i.e. bio gas stove for cooking</strong></td>
<td><strong>Purchase cost effective stoves and extras.</strong></td>
<td><strong>Purchase cost effective stoves and extras.</strong></td>
</tr>
<tr>
<td><strong>Not a labour intensive process</strong></td>
<td><strong>Works best on dairy farms with 800 cows.</strong></td>
<td><strong>The area and specific circumstances are to be closely studied to work out the optimum setup.</strong></td>
</tr>
<tr>
<td><strong>Can be used to provide for an alternate cooking technique to biomass stoves, kerosene and wood fire.</strong></td>
<td><strong>Positive impact on deforestation</strong></td>
<td><strong>Solves odour issues. Despite utilising forms of animal waste the Biodigester actually depletes the smell of raw waste.</strong></td>
</tr>
</tbody>
</table>

### 4.3.2. The Next Steps

The implementation of a Biogas plant in the community will be of great benefit. Not only will the village be gaining a renewable, reliable back up power source they will also be gaining an economic advantage. Although being a costly installation, the Biodigester will pay for itself in electricity generation and through the possible sale of by products.

In order for the installation to be accepted by the community they will need to be educated on the processes of the digester and the dangers related to the process. Despite this process involving possible aspects of danger it does not present any extra danger, in fact it poses less of a danger, to some of the methods already being used by the community such as biomass stoves, wood fires and kerosene cooking elements. With education the people of Devikulam can be informed of the precautions to take when working around the Biodigester and the correct methods for interaction with the digester. Training should also be given for the correct method of maintenance which will need to be carried out by the villagers. Supervision should be supplied by Biogas Technology knowledgeable persons who also understand the culture and needs of the community. This supervision should continue for a reasonable time to ensue the people are able to understand the full process and can learn how to rectify common problems as they occur. Also, following the initial installation, training and supervision process, the people of Devikulam should be able to have constant contact to a help line where if they are unsure of any issues pertaining to the system they can receive immediate assistance. If required the community will not only be able to receive help through oral instruction but also will be provided with physical assistance if needed. Through the implementation of training courses and supervision the people of Devikulam should be able to
recognise the benefits the Biodigester can offer to the community and to their way of life and feel comfortable enough to use it, having full knowledge of the support they will receive throughout the transition.
5. EVALUATION

5.1 EVALUATION & TESTING PLAN

The first to be conducted for the suitability of the tank is whether the planned generator can actually supply Devikulam with enough power during a brown-out. To begin, it will be assumed that the GM Kohler 53kW generator is running at full capacity during a brownout.

In Devikulam there are a number of electrical appliances in use, namely:

- 184 light bulbs
- 20 tube lights
- 53 fans
- 22 rice grinders
- 10 mixers
- Fridges

For power consumption, the following assumptions concerning power usage will be made:

- Light bulb = 50W
- Tube light = 57W (based on minimum/maximum consumption values of 33 and 82W respectively)
- Fan = 35W
- Fridge = 4kW per day

Power usage of mixers and rice grinders is negligible since they are not operational all hours of the day.

Based on these averages and assumed figures the total, immediate power consumption of Devikulam is most likely equal to 24,195W, or 24kW. Given that the generator is capable of power outputs of up to 53kW, this shows that the generator will be more than capable of providing sufficient power during a brownout.

There is also the issue of determining how much methane can be produced in one biodigester by a set quantity of waste. This is necessary knowledge since the potential methane production must be known before estimates for true power production can be made.

In existence around the world are a large number of small biodigesters. Some people have even filmed and uploaded demonstration and construction videos onto the website YouTube which explain how a biodigester can be made from ordinary materials and how it produces methane gas. Using this resource, it is possible to construct a small biodigester to conduct an experiment to measure how much methane can be theoretically produced.

A measured quantity of waste can be added to the biodigester and fed with a known quantity of oxygen (to make sure the digestion can occur). The reaction can be left to take place for a period of
time, and the products released. The methane that is produced can then be released and trapped in another container for subsequent measurement.

Since the heat of combustion, i.e. the amount of energy released by one molecule of methane, is known, no experiments are necessary to determine this value. This value, endorsed by the International Union of Pure and Applied Chemistry (IUPAC), can instead be used to calculate how much energy, and subsequently how much power, can be released by a given quantity of methane.

5.2 SAFETY HAZARDS & CONTROLS

Process safety is a major concern in the use of the Biodigester. The world is full of examples of the impacts of oil, gas & chemical accidents, from major environmental disasters to major explosions causing hundreds of deaths. The biodigester proposal does not carry the potential for a major international incident, nor is a process incident highly likely. However, the fact that there are potential safety events which could cause fatalities, contamination and local outrage means that tight controls must be kept on the facility.

There are several potential high consequence / low likelihood potential safety events to which controls have been addressed:

- Loss of containment of Biogas. Being exposed to high concentrations of biogas in the air can cause health problems and even fatalities if the concentration is high enough – especially when the area is a confined space such as the biodigester pit. To control potential exposure to gas, fixed gas monitors will be placed proximate to the gas facility on three sides to detect any leaks into the air. All pipes carrying gas will be carefully maintained and tagged with an ID. The person responsible for the biodigester will be trained in gas safety and will be on call to manage any major events. When any maintenance is being carried out inside the digester or close to it, the system will be purged, correct breathing apparatus will be used, and there will be a confined space responsible officer on hand to control movements in and out of the confined space and make sure there is only one person (authorized) in the hole at any one time.

  The potential loss of gas is also the main reason the desulfuriser is included, as sulfur compounds corrode pipes.

- Fire / explosion due to loss of gas inside or outside the digester. The controls for this are similar to the controls for loss of gas. The pressure is controlled to reduce the risk of explosion. The tank is located underground so any potential accident inside the biodigester would have a lesser impact. In the case of any gas fire, the village would be evacuated to the lake area - plans would be put in place for this potential scenario.

- Overpressure related explosions. If gas were to fill up in the digester without being let out, despite the tank being designed to hold against the soil around it, the pressure would grow so high that an overpressure related breakage or even an explosion would ensue. The tank is equipped with a pressure measuring instrument which records the gas levels and pressure. When the pressure reaches a certain level, the flare would be turned on and the gas would be flared off until the gas fell below that level. The flare would be located away from and above the tank to decrease the risk of fire.
There would be a villager responsible for the biodigester who would also act as a safety warden for the village, and who would be highly trained in gas safety. Access controls would be placed around the tank itself. The electrical and mechanical maintenance officers would also be trained in gas safety.

Other hazards involved in the use of the entire system include the general maintenance of the gas system and electricity system and the way in which the villagers use them. Injuries such as burns and electrocution could be reduced through good and frequent maintenance of the system, and through supporting and training the villagers in household safety.

### 5.3 COST EVALUATION

To provide some sort of ‘testing’ to satisfy the financial criteria, i.e. criteria 1 and 4 as specified in Section 1.3, an accurate yet feasible costing must be provided. The tank itself will be made of sheet metal, since we are very familiar with the properties of steel and prices for steel components are readily available to us as a result of our working environment.

Also included in this cost analysis is the costing for the communal kitchen building proposed in Section 4.2.3 of this report.

For a design made of steel, the tank itself would be constructed from sheet metal, with wall thickness being between 2-5mm. This should be enough to contain the gas without buckling under pressure, or corroding caused by reactions with any by-products from the decomposition reaction occurring inside the tank.

The costing for all of the tank components has been formulated (see Appendix 2).

Other costs to be considered aside from tank components are things such as a simple security fence to stop locals from venturing too close to the tank itself, fixed gas monitors that are a necessary safety requirement, a control computer, and the cost of steel piping.

A suitable computer for the site would be a HP Compaq Minitower PC. These computers are already in use in many businesses around Australia, and are more than capable of having gas monitoring software installed on them. The specifications and total price are as follows:

**Table 5.3.1 Control computer specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Specification Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>Intel Pentium Dual-Core (2.93 GHz)</td>
</tr>
<tr>
<td>Operating System</td>
<td>Windows 7 (32 bit)</td>
</tr>
<tr>
<td>Memory</td>
<td>2GB DDR3 SDRAM</td>
</tr>
<tr>
<td>Hard Disk</td>
<td>160GB SATA</td>
</tr>
<tr>
<td>Operational Humidity</td>
<td>10-90% Relative Humidity</td>
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<tr>
<td>Operating Temperatures</td>
<td>10-35°C</td>
</tr>
<tr>
<td>Power usage</td>
<td>100-240V (AC)</td>
</tr>
<tr>
<td>Monitor</td>
<td>AOC 18.5in LED</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>AUD $1,327</strong></td>
</tr>
</tbody>
</table>
The last three system specifications mentioned in Table 4.2 of particular importance, as low power usage will reduce costs of running the system, and the control computer itself must be able to work in hot, humid conditions typically seen in southern India.

The other required components include fencing for the tank compound, which can be provided as reinforcing mesh by Bunnings. The mesh is a standard panel of 2400mmx1200mm steel mesh, costing AUD $68.57 per panel. To create the desired ~5mx5m, 4 panels are needed to create a 4.8mx4.8m perimeter, bringing the total cost to AUD $274.28.

Steel piping can be sourced from OneSteel Tube products produced at their plant in Sydney and supplied from a Port Kembla outlet. 25 metres of pipe is needed to supply gas to the generator and the communal kitchen. The price of steel piping is determined by the properties of pipe steel, which has a density of 7 tonnes per cubic metre and costs $900 per tonne (BSI 2011). The piping for this project equates to 2.7 cubic metres of material, making the material cost $2,430.

Another aspect of cost that must also be considered is the cost of labour in Devikulam. Part of the manufacturing plan as specified in Section 4.2 is to involve the community by instructing them in the use of the biodigester, and by employing them to dig the hole that the tank will fit in. Based on average figures obtained from a survey conducted on Devikulam located in the EWB Knowledge Hub, it can be assumed that the average yearly income of any one person in the village is equal to 30,600Rs, or AUD $639 per annum. Therefore, to employ 30 people to dig the required pit would cost, on average, AUD $19,710 per annum. However, since the job of digging may only take 3 weeks or so, the amount paid to 30 workers is more equal to $1,106.

Therefore, the total cost associated with constructing this tank is equal to:

Table 5.3.2 Total Tank cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control computer</td>
<td>$1,327</td>
</tr>
<tr>
<td>Steel piping</td>
<td>$2,430</td>
</tr>
<tr>
<td>Gas/pressure monitors</td>
<td>$520</td>
</tr>
<tr>
<td>Steel fencing</td>
<td>$274.28</td>
</tr>
<tr>
<td>Labour costs</td>
<td>$1,106</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$5,657.28</strong></td>
</tr>
</tbody>
</table>

The community stoves are to be made in 3mx5m sections, allowing for future expansion should the need arise. Also required are basic 2-burner gas barbecues, sourced from Bunnings and priced at $89 each, of which 3 are needed per 3x5m section (with 24 needed overall). Also required are mud bricks for the barbecue stands themselves, to be made from 168 half-weight bricks at $2.30 per brick, or $386.40 total. 72m² of Colorbond steel is also needed to form the roof of the structure, and 90m² for the walls, which will also be sourced from Bunnings as 1.8x1.2m corrugated panels, at $18.90 per panel. 33 plates will be needed to cover 72m², and 42 plates for the walls, bringing the cost to $1,411.20. Labour costs similar to those for the tank must also be factored in.

Therefore, the total cost associated with constructing one community stove is equal to:
### Table 5.3.3 Total Stove cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber framing</td>
<td>$850</td>
</tr>
<tr>
<td>2-burner gas barbecues</td>
<td>$267</td>
</tr>
<tr>
<td>Mud bricks</td>
<td>$386.40</td>
</tr>
<tr>
<td>Colorbond roofing</td>
<td>$623.70</td>
</tr>
<tr>
<td>Labour costs</td>
<td>$1,106</td>
</tr>
<tr>
<td>Colorbond walls</td>
<td>$787.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$4,020.60</strong></td>
</tr>
</tbody>
</table>

Subject to community consultation, three of these are likely to be constructed.

The total cost for the tank components, as detailed in Appendix 2, comes to $23,865.94. As a result, the cost of the entire project is equal to:

### Table 5.3.4 Overall System cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank system &amp; latrine components</td>
<td>$23,865.94</td>
</tr>
<tr>
<td>Tank construction</td>
<td>$5,657.28</td>
</tr>
<tr>
<td>Community stoves x 3</td>
<td>$12,061.80</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$41,585.02</strong></td>
</tr>
</tbody>
</table>

#### 5.4 CONCLUSION

The proposal for the Biodigester system, creating a gas supply, a backup electricity supply, a hygienic toilet facility, a safe and modern cooking facility, and a supply of fertiliser, for a relatively low outlay of capital, represents an enormous potential value addition to the community of Devikulam. If implemented, with community consultation and education, the system would improve living standards, hygiene, safety, and agriculture, while creating several skilled jobs in the local community and creating opportunities for business. The proposal has been found to be not only a superior path to other potential energy solutions, but safe, cost effective, and easy to test on a small scale. Though a major construction, through community involvement, local material use and prefabrication thanks to innovative design, it is estimated that the facility could be constructed within 16 weeks subject to further consultation. Taking all of these factors into consideration, the proposal is strongly recommended for implementation.


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**APPENDIX 1 – MEETING MINUTES**

Minutes for Team Meeting No# 1 Tuesday 09/08/2011: Design Tutorial

Agenda:

1. Read EWB design brief 
2. Choose a problem area 
3. Discuss possible solutions to area 
4. Assign corrective action for next meeting.

Corrective Actions:

1. Lani was given an action to investigate the frequency of power outages in the villages, their duration and how many households currently use power. 
2. Najdo and Thomas we given actions to research alternative solution to the backup power supply problem. 
3. Peter was given an action to perform further research on the region e.g. Climate, topography and geography.

Minutes for Team Meeting No# 2 Friday 19/08/2011: University Library

Agenda:

1. Allocate tasks for preliminary draft of design report based on provided design template. 
2. Define our solution (Choose option) 
3. Discuss what sections of the report must be completed by Tuesday (23/08/2011) 
4. Assign corrective action for next meeting.

Corrective Actions:

1. Najdo was given an action to cover section on of the design report (Problem statement) 
2. Peter is to create the evaluation section of the report 
3. Thomas is to design the solution and collate report 
4. Lani is to discuss the current design options.
Minutes for Team Meeting No# 3 Wednesday 23/08/2011: University Library

Agenda:

1. Quick overview of draft report so far
2. Edit and amend report
3. Discussion on each team members input.
4. Assign corrective action for next meeting.

Corrective Actions:

1. Thomas to complete table of contents
2. Future date of meeting to be set (6/09/2011)

Minutes for Team Meeting No# 4 Tuesday 6/9/2011, 1:00, University Library level 2

Agenda:

1. Feedback from draft report. Generally very positive. Some sections need to be improved by team members. Followups assigned to Thom to continue working on detailed design sections, Lani to collate references, Najdo to begin cost analysis & evaluation once detailed design is complete, Peter to continue working on body of report and improvements to plans and collation.
2. Discussion of the detailed design was held in order to familiarise all team members with working parts/implementation.
3. A decision was made not to begin on construction of the model until detailed design is fully completed.
4. Next meeting to be held 27/9, team members to continue submitting sections for review & collation.

Minutes for Team Meeting No# 5 Tuesday 27/9/2011, 1:00, Engineering Faculty

Agenda

1. Final report is drafted and ready for review. Additions still to be made include last of the engineering drawings, checking of references, cost analysis, and improvements to manufacturing, safety and cultural plans.
2. Plan to construct model on 6/9 and 10/9. Decisions were made as to exact design of the model and materials to be used.
3. By 10/9 report should be fully collated and ready for final submission. Design of the report (including all sections) to be polished off between 11/9 and 12/9.
4. Team discussed the overall project and comments were collected for addition to the final Team Reflection.
APPENDIX 2 – FULL COSTINGS FOR TANK COMPONENTS
<table>
<thead>
<tr>
<th>Structure Section</th>
<th>Component</th>
<th>Price 1</th>
<th>Price 2</th>
<th>Price 3</th>
<th>Total Price</th>
</tr>
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<tbody>
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<td>$700.00</td>
<td>$1800.00</td>
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<td>$135.00</td>
<td>$150.00</td>
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<tr>
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Total Cost for Tank / Latrine materials: $23,865.94
APPENDIX 3 – PHYSICAL MODEL OF TANK SYSTEM

Desulfuriser
Cutaway tank
Latrine

Desulfuriser
Cutaway tank
Latrine
APPENDIX 4 – COMPOSITION OF BIOGAS

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Concentration (%)</th>
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<tbody>
<tr>
<td>Methane</td>
<td>50-70</td>
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<tr>
<td>Carbon dioxide</td>
<td>30-40</td>
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<tr>
<td>Hydrogen</td>
<td>5-10</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1-2</td>
</tr>
<tr>
<td>Water</td>
<td>0.3</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>Trace amounts</td>
</tr>
</tbody>
</table>

Concentrations depend on composition of feedstock and amount of time left to decompose.

APPENDIX 5 – CAD DRAWINGS OF BIODIGESTER

Drawings numbered 0#-1# refer to the Community Latrine.

Drawings numbered 2# refer to the Biodigester.

Drawings numbered 3# refer to the Desulfuriser and Storage tank.

Drawings numbered 4# refer to the Community Stoves.