STRENGTHENING THE FIJI BIOGAS PROGRAMME

A study for

the Department of Energy,

Government of Fiji

REPORT 3 of 5:

Criteria and technology specifics

AGAMA Energy (Pty) Ltd
P O Box 4, Lynedoch, 7603, South Africa
Phone: + 27 21 881 3282 // Fax: + 27 881 3412,
www.agama.co.za

Greg Austin
November 2006
ACKNOWLEDGEMENTS

The author thanks the assistance of Neil Parker, John Hulme, Mark Wells and Brenda Gold in compiling the information in this report.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii  
TABLE OF CONTENTS iii  
LIST OF FIGURES v  
LIST OF TABLES v  
LIST OF ABBREVIATIONS vi  

1. Introduction 1  

2. Criteria for the dissemination of biogas technology 2  
2.1 Programme-level exclusion criteria 2  
2.2 Programme-level primary success criteria 2  
2.3 Ideal conditions for biogas implementation 2  
2.4 Site evaluation guidelines 4  

3. Digester types 5  
3.1 Floating dome digesters 5  
3.2 Fixed Dome Digesters 6  
3.2.1 The Chinese Digester 6  
3.2.2 The Janata Model 7  
3.2.3 Modified Janata solid state digester 8  
3.2.4 Deenbandhu biogas digester 9  
3.2.5 Himshakti Biogas Plant 10  
3.2.6 The CARMARTEC Model 10  
3.2.7 The Nepalese Digester 11  
3.3 High rate anaerobic reactors 11  
3.3.1 Upflow Anaerobic Sludge Blanket (UASB) Reactor 11  
3.3.2 Expanded Granular Sludge Bed Reactor 14  
3.3.3 Anaerobic Baffled Reactor: 15  
3.4 Flexible Plastic Digesters 16  
3.4.1 Red Mud Plastic Digester 16  
3.4.2 Polyethylene Tube Digesters 17  
3.5 The Plug-Flow Digester 18  
3.6 Anaerobic Lagoons 19  
3.7 Batch and Dry Fermentation 19  

4. Fiji digester design 21  
4.1 Description of the digester 21  
4.2 Feeding materials and loading rates 23  
4.3 Technical specifications 23  
4.3.1 Planning 23  
4.3.2 Siting 23  
4.3.3 Selecting the correct size 24
4.3.4 Materials determination 25
4.3.5 Labour requirements 26
4.3.6 Plant and equipment 26
4.3.7 Jointing and bedding of pipework 26
4.4 Sequence of work 28
4.4.1 Gas installation 29
4.4.2 Risk assessment 31
4.5 Drawings 35

5. Quality management 36

6. Commissioning 37

7. Operations and Maintenance 39
   7.1 User training 39
   7.2 Troubleshooting 40

8. Bioslurry 42
   8.1 Importance of bioslurry for crop production 42
   8.2 Characteristics of digested slurry 42
   8.3 Utilization of Digested Slurry 43
      8.3.1 Application of liquid bioslurry 43
      8.3.2 Application of dried bioslurry 43
      8.3.3 Utilizing bioslurry for making compost 43
   8.4 Influence of slurry on crop yields 44

References 45

Annex A: Drawing of the 4 m³ digester 48

Annex B: Site evaluation guideline and checklist 49

Annex C: Anaerobic Digester Comparison Chart 54
LIST OF FIGURES

Figure 1: The KVIC floating drum model...............................................................................5
Figure 2: The Chinese biogas digester ..................................................................................7
Figure 3: Janata Biogas Digester Model ............................................................................. 8
Figure 4: Modified Janata for solid state digestion of cattle manure .................................. 8
Figure 5: A typical Deenbandhu biogas digester ................................................................ 9
Figure 6: The CAMARTEC fixed dome model.....................................................................10
Figure 7: The Nepalese biogas digester................................................................................ 11
Figure 8: A simple UASB Reactor ...................................................................................... 12
Figure 9: ZERI Fibreglass UASB Digester ......................................................................... 13
Figure 10: ZERI Concrete UASB ...................................................................................... 14
Figure 11: Settling Tank for UASB digester effluent............................................................14
Figure 12: The basic EGSB design..................................................................................... 15
Figure 13: Anaerobic Baffled Reactor (ABR) ..................................................................... 15
Figure 14: Red mud digester ............................................................................................. 16
Figure 15: Bag-Red Mud (Taiwan, China) Digester.............................................................16
Figure 16: Typical polyethylene tube digester ................................................................... 17
Figure 17: Typical Flexible Plastic Tube Digester configuration......................................... 17
Figure 18: Plug Flow Digester .......................................................................................... 18
Figure 19: A photo of the anaerobic lagoon at the Cal Poly Dairy taken in 2003...............19
Figure 20: A typical batch digester ................................................................................... 20
Figure 21: Drawing of the 4 m³ digester ........................................................................... 22
Figure 22: Typical section through a pipe trench.................................................................27

LIST OF TABLES

Table 1: Programme-level criteria applied to Fiji .................................................................3
Table 2: Comparative performance of Janata Biogas plants .................................................9
Table 3: Digester size as a function of the available feedstocks ..........................................23
Table 4: Risk assessment for building works.....................................................................32
Table 5: Risk assessment for gas installations.................................................................. 33
Table 6: Common problems with biogas plants and remedies .........................................40
Table 7: Nutrients available in bioslurry and manures .......................................................44
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
<td>Department of Energy</td>
</tr>
<tr>
<td>EGSB</td>
<td>Expanded Granular Sludge Bed Reactor</td>
</tr>
<tr>
<td>FRP</td>
<td>Fibre Reinforced Plastic</td>
</tr>
<tr>
<td>GOF</td>
<td>Government of Fiji</td>
</tr>
<tr>
<td>GW</td>
<td>GigaWatt (kW x 10^6)</td>
</tr>
<tr>
<td>GWh</td>
<td>GigaWatt hours (kWh x 10^6)</td>
</tr>
<tr>
<td>HRT</td>
<td>Hydraulic Retention Time</td>
</tr>
<tr>
<td>KVIC</td>
<td>Khadi and Village Industries Commission</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
</tr>
<tr>
<td>Mt</td>
<td>MegaTonne (tonne x 10^6)</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt (kW x 10^3)</td>
</tr>
<tr>
<td>MWh</td>
<td>Mega Watt Hours (kWh x 10^3)</td>
</tr>
<tr>
<td>NBP</td>
<td>National Biogas Programme</td>
</tr>
<tr>
<td>PJ</td>
<td>PetaJoule (J x 10^{12})</td>
</tr>
<tr>
<td>TSC</td>
<td>Total Solid Content</td>
</tr>
<tr>
<td>UASB</td>
<td>Upflow Anaerobic Sludge Blanket</td>
</tr>
<tr>
<td>ZERI</td>
<td>Zero Emission Research and Incentives</td>
</tr>
</tbody>
</table>
1. **Introduction**

This is the third report in a series of five reports in fulfilment of the terms of reference for Strengthening the Biogas Programme. It provides the balance of the specified deliverables as specified in that Terms of Reference, namely:

1. Develop a specification for appropriate models of digesters to be used in Fiji, including
   - Produce an inventory of the common models of biogas plants in use that can be applied to the country’s situation. The inventory is to also include biogas energy conversion systems for heating, lighting and electricity production;
   - For each model that can be locally used, provide detail information including waste requirements, gas production, materials specification, strengths and weaknesses of each model;
   - Recommend the most appropriate model(s) to be used in the country
2. Develop criteria for selecting sites for biogas projects, including
   - Survey and evaluate three potential sites for biogas plants;
   - Develop a criteria for assessing potential sites;
   - Provide practical training to DOE staff on the use of the assessment and evaluation criteria

This report elaborates a range of aspects relating to the NBP, including criteria for programme and site development, relative advantages and disadvantages of different digester types, quality management, commissioning, and operations and maintenance. The Fiji digester design is also described, and a site selection guideline/form provided as an Annex. The report closes with a description of the benefits and utilisation of bioslurry to improve crop yields.
2. **Criteria for the dissemination of biogas technology**

There are essentially two levels of criteria relating to biogas implementation. The first is a programme-level set of criteria, and the second is a site-specific set of criteria. Both sets are covered here and reviewed against the Fiji context. This section also includes a list of those conditions that can be thought of as ideal for programme and project implementation.

### 2.1 Programme-level exclusion criteria

If only one of the following criteria is evident in a country/region, then the widespread dissemination of simple household biogas plants is not possible:

- too cold or too dry
- very irregular or no gas demand
- less than 20 kg dung/day available to fill the plant or less than 1,000 kg live weight of animals per household in indoor stabling or 2,000 kg in night stabling
- no stabling or livestock in large pens where the dung cannot be collected
- no building materials available locally
- no or very little water available
- integration of the biogas plant into the household and farm routines not possible
- no suitable institution can be found or developed for dissemination

### 2.2 Programme-level primary success criteria

Each of the following factors will lead to severe problems in biogas dissemination if not adequately met. Accompanying measures, particularly modified technical developments, high financial promotion or additional organizational structures within the dissemination program are necessary to guarantee project success.

Table 1 summarises the key programme level criteria as applied to Fiji.

### 2.3 Ideal conditions for biogas implementation

If the following conditions are fulfilled then household biogas plants will definitely be a success:

- even, daily temperatures over 20°C throughout the year
- regular gas demand approximately corresponding to gas production
- full stabling of animals (zero-grazing) on concrete floors – noting that this practise is not in use in Fiji
- at least 20 kg/day dung/feedstock available per plant
- dairy farming is the main source of income
- use of organic fertilizer is traditionally practiced
- farmers are owners of the farm and live primarily on the farm. Farm products are their main source of income.
- Digesters can be located in favourable positions to the stables and to the point of gas consumption
- operating the biogas plant can be integrated into the normal working routine of the house and the farm
• gas utilization and attendance of the plant can be clearly regulated within the household
• moderate price of plant in relation to the income of the target group
• economically healthy farms open to ‘modernization’
• insufficient and expensive supply of fossil sources of energy
• building materials and gas appliances available locally
• qualified artisans exist locally
• promoter has access to and experience in contact with the target group
• promoter has good experience in cooperating with the private sector
• promoter has experience in programs comparable to biogas dissemination
• political will of the government to support biogas technology and other small and medium-scale farm technologies
• secured financing of the dissemination structure

Table 1: Programme-level criteria applied to Fiji

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Fiji status (Good, Medium, Weak, Unknown)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>low income or unstable economic situation of the target group</td>
<td>M</td>
<td>Farmers with animals are considered generally well-off, while those without are not. Over 80% of rural households have animals.</td>
</tr>
<tr>
<td>insecurity regarding land tenure</td>
<td>W</td>
<td>One would need to cross-check the number of farms with sufficient resources against those that are coming up for lease expiry in the medium term (10 years)</td>
</tr>
<tr>
<td>unfavourable macro- and micro-economic conditions</td>
<td>G</td>
<td>Financial analyses indicate a positive IRR for biogas digesters</td>
</tr>
<tr>
<td>gas appliances not available regionally or nationally</td>
<td>M</td>
<td>In the short-term will have to modify and/or import appliances</td>
</tr>
<tr>
<td>irregular gas demand</td>
<td>G</td>
<td>LPG costly</td>
</tr>
<tr>
<td>very good supply of energy throughout the year, therefore only moderate economic incentives for the biogas plant</td>
<td>G</td>
<td>LPG costly</td>
</tr>
<tr>
<td>high building costs</td>
<td>M</td>
<td>Cost of BGD is 53% of GDP&lt;sub&gt;PPP&lt;/sub&gt;</td>
</tr>
<tr>
<td>low qualification of artisans</td>
<td>G</td>
<td>Good artisan resources</td>
</tr>
<tr>
<td>limited access to the target group by the promoter</td>
<td>G</td>
<td>Good access</td>
</tr>
<tr>
<td>weak structure of the promoter</td>
<td>G</td>
<td>Good structure</td>
</tr>
<tr>
<td>no substantial interest of the government is evident</td>
<td>G</td>
<td>Good interest and support.</td>
</tr>
</tbody>
</table>
2.4 **Site evaluation guidelines**

The guideline and checklist in Annex B: Site evaluation guideline and checklist, can be used by the project planner to assess resources, identify risks and make initial estimates of issues relating to the project planning.
3. **Digesters types**

This section presents the history and current developments of biogas technology internationally. Annex C: Anaerobic Digester Comparison Chart provides a full description of the technical, financial and other benefits/disadvantages of the digester types.

3.1 **Floating dome digesters**

This discussion is limited to reviewing the Khadi and Village Industries Commission (KVIC) model in India, which has become the pervasive floating dome design. In 1950, Patel designed a plant with a floating gas holder which became popularised the adoption of biogas in India. The KVIC digester has a cylindrical shaped floating biogas holder on top of the well-shaped digester. As the biogas is produced in the digester, it rises vertically and gets accumulated and stored in the biogas holder at a constant pressure of 8-10 cm of water column. The biogas holder is designed to store 50% of the daily gas production. Therefore if the gas is not used regularly then the extra gas will bubble out from the sides of the biogas holder [1].

![Figure 1: The KVIC floating drum model](image)

*Source: [1]*

The Khadi and Village Industries Commission (KVIC) of Bombay began using the Patel model biogas plant in a planned program in 1962, and since then it has made a number of improvements in the design. The most common digesters are of 6 and 8 m$^3$ gas production capacity. The digester is designed for 30, 40 and 55 days' retention time: the lowest time applies to the hot southern States, the highest to the cooler northern States.
Where minimum temperatures go down to 0°C, such as the hilly areas of Northern India, the retention time is increased to 80 days.

The reactor is fed semi-continuously through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe. When the reactor has a high height: diameter ratio, a central baffle is included to prevent short circuiting.

Construction costs vary according to ambient temperatures, for which partial compensation is allowed for by subsidies. The main material fed is cattle manure. At community plant level, nightsoil is digested in a mixture with cattle dung, and at large farm level other types are being introduced, to digest materials such as water hyacinth. The drum was originally made of mild steel until fibreglass reinforced plastic (FRP) was successfully introduced to overcome the problem of corrosion. Nearly all new digesters are equipped with FRP gas-holders.

The cost of a mild steel gas-holder was approximately 40 to 50% of the total cost of the plant. FRP gas-holders are 5 - 10% more expensive than the steel drum. The following Table gives the cost of FRP drums in two different enterprises visited.

The total solid content percentage of influent is typically 10%, and the daily average gas yield varies from 0.20 to 0.60 volume of gas per volume of digester ratio in cold to warm climates.

With the introduction of fixed dome Chinese model plant, the floating drum plants became less popular because of comparatively high investment and maintenance cost along with other design weaknesses. Some countries, such as Nepal, phased out the installation of KVIC design plants from as early as 1986 [6].

### 3.2 Fixed Dome Digesters

Fixed Dome digester have the advantage over floating dome digesters in that there are no moving parts which makes local construction and maintenance cheaper and easier [2], however these cost savings may diminish with scale with this design, so these systems may be more appropriate for small-scale users. It is also less susceptible to steep variations in ambient temperature.

One disadvantages for the fixed-dome design is that gradual accumulation of sludge is likely within the system, making periodic cleaning necessary [2]. The construction of fixed dome structures requires good quality materials and expert construction using skilled masons will produce a satisfactory biogas plant [3].

#### 3.2.1 The Chinese Digester

After the construction of a fixed dome biogas digester in Jiangsu, China as early as 1936 considerable research has been carried out in China on various digester models. The common family sized fixed dome digester has become the popularised throughout China and its design and installation procedures are well advanced and already standardized at national level.

A comprehensive training programme has been developed to complement China's aggressive 2003-2010 National Rural Biogas Construction Plan which plans to increase biogas use by 11 million to a total of 20 millions households by 2005, to make one in ten farmer's households a biogas user; although the rate would reach 15 percent in some areas. By 2010, China would increase biogas-using households by a further 31 million to a total of 50 million, so the rate of use would reach 35 percent. From 2003, a government subsidy of 1 000 Yuan (about US$ 150) would be provided for each biogas digester. [4]
Figure 2: The Chinese biogas digester

Source: [4]

This reactor consists of a gas-tight chamber constructed of bricks, stone or poured concrete. A brick dome may be constructed on an umbrella-shaped framework or a concrete cast-in-place digester used. Both the top and bottom of the reactor are hemispherical, and are joined together by straight sides. The inside surface is sealed by many thin layers of mortar to make it gas tight, although in the old type digesters gas leakage through the dome was often a major problem in older models although this has been remedied in the newer designs. The digester is fed semi-continuously (i.e. once a day), the inlet pipe is straight and ends at mid-level in the digester. There is a manhole plug at the top of the digester to facilitate entrance for cleaning, and the gas outlet pipe exits from the manhole cover.

The gas produced during digestion is stored under the dome and displaces some of the digester contents into the effluent chamber, leading to gas pressures in the dome of between 1 and 1.5 m of water. When biogas gets collected in the dome, it exerts pressure on the liquid driving the fluid in the inlet and outlet chambers. Thus when gas is used up, the liquid level in the inlet and outlet goes down. This creates quite high structural forces and is the reason that the reactor has a hemispherical top and bottom. In one variation, the displaced effluent flows onto the roof of the reactor thus enabling the roof to withstand the gas pressure more easily.

The inside water level at ambient pressure is at 95% of total volume. The gas pressure in fixed-dome digesters is equal to, or below, 120 cm of water. Ratios of key dimensions are kept constant, e.g. diameter to height of the cylinder is 2:1. The HRT, for both cow and pig manure, is 35 - 40 days at total solids concentrations of 5 - 8% and 4 - 7%, respectively. Gas production per digester volume varies from 0.15 to 0.6 m$^3$/m$^3$ per day, depending on the ambient temperature [1].

3.2.2 The Janata Model

This type of digester was disseminated by the Indian NGO network of AFPRO and many government agencies and was the first fixed dome plant based on Chinese technology. It is now discontinued mostly due to dome cracking. These units were built of brick or stone masonry, underground. The plant consists of an inlet tank, digester, an outlet tank and gas distribution system. The gas evolved is collected over the digester chamber in the dome shaped roof portion, which also contains tubes for removing the gas. Like the
Chinese digester, the biogas gets collected in the dome exerts pressure on the liquid driving the fluid in the inlet and outlet chambers so that when the gas is used up, the liquid level in the inlet and outlet drops down.

**Figure 3: Janata Biogas Digester Model**

*Source: [5]*

The Janata system is about 30% cheaper to construct than a KVIC model of the same capacity. The total solid content of the influent is typically between 8 and 10% and nearly all sizes of Janata digesters are designed for 60 days' retention time. Gas production per digester volume is on average 0.33 m$^3$/m$^3$ per day [3].

### 3.2.3 Modified Janata solid state digester

The modified Janata digester has been proven a successful method of producing biogas and nutrient rich slurry from undiluted cattle manure and produces 52% more gas than the more expensive original Janata model [5].

**Figure 4: Modified Janata for solid state digestion of cattle manure**

*Source: [5]*
Table 2: Comparative performance of Janata Biogas plants

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Common design</th>
<th>Modified plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSC, %</td>
<td>8 – 10</td>
<td>14 – 16</td>
</tr>
<tr>
<td>Gas yield, l / kg dm</td>
<td>134</td>
<td>205</td>
</tr>
<tr>
<td>TS degradation, %</td>
<td>25</td>
<td>37</td>
</tr>
<tr>
<td>VS degradation, %</td>
<td>35</td>
<td>49</td>
</tr>
<tr>
<td>“Weekly mean ambient temperature”</td>
<td>9-35° C</td>
<td></td>
</tr>
</tbody>
</table>

Source: [5]

3.2.4 Deenbandhu biogas digester

In an effort to reduce the construction costs, the Deenbandhu model introduced in 1984 by the Action for Food Production (AFPRO), New Delhi. In India, this model proved 30 percent cheaper than Janata Model. It also proved to be about 45 percent cheaper than a KVIC plant of comparable size. Deenbandhu plants are made entirely of brick masonry work with a spherical shaped gas holder at the top and a concave bottom [6]. The “Deenbandhu” Biogas Plant, which is the most popular model in India, accounting for over 80% of the 150,000 household plants built each year [7].

Figure 5: A typical Deenbandhu biogas digester

Source: [8]

Performance of the Janata and Deenbandhu fixed dome biogas plants for anaerobic digestion of dairy manure was evaluated under the conditions of a hilly region. In contrast to Janata, the Deenbandhu biogas plant was found to be not only cheaper on the basis of cost/m³ rated capacity of the plant, but it also produced more gas per unit of manure fed and per unit of digester volume in addition to maintaining a consistent rate of gas production during subsequent years from initial charging. The higher production of gas by 28.5% and 12.5% per kg of manure fed and 49.5% and 28.9% per m³ of digester volume was observed from this plant for highest 24°C and lowest 14°C digester temperatures of the plants for the months of July and December respectively [9].
The estimated cost of a common 2 cubic metre capacity family type fixed dome Deenbandhu Model Plant is about Rupees (Rs.) 12,000 in North Eastern States, Rs. 10,500 in other hilly areas and Rs. 8500 in plain areas [9].

3.2.5 Himshakti Biogas Plant

Salient Features: Rated capacity 1 & 2 m$^3$/day, combines good features of Janata and Deenbandhu designs, easier construction, suitable for hilly terrains, stone blocks available in hills may also be used for construction.

Performance: Average yearly gas yield per kg dung higher than Deenbandhu plant by about 10%.

Cost: NPR 7,600 (US$ 167) for 1m$^3$ capacity plant & NPR 11,900 (US$ 262) for 2 m$^3$ capacity plant [9]. If the stones available from excavation of soil are used for the construction of the plants, the costs of these plants can be lower by 9%.

Performance: On an annual average, the rate of daily biogas produced per kg cattle manure fed to the developed 1 m$^3$ and 2 m$^3$ Himshakti biogas plants was found to be 13.83% and 17.02%, respectively, higher compared to Deenbandhu biogas plan presently propagated and suitable for clay soils. On per unit digester volume basis, these plants were also found to produce a higher rate of 18.1% and 34.3% biogas compared to the later plant [9].

3.2.6 The CARMARTEC Model

Figure 6: The CAMARTEC fixed dome model

Source: [9]

The CAMARTEC model was developed in the 1980s in Tanzania. It has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak / strong ring. Since 1992 the "weak-ring" has been omitted as it is assumed that the change in cross-section below the "strong-ring" automatically functions as a predetermined breaking point. When the cattle were fed on king-grass, there were frequently problems with scum in the plant. The high position of the pipe to the compensation chamber presumably made this problem worse. Since 1992, the digester and compensation chamber have been connected by a shaft running from the bottom of the digester up to under the "strong-ring". In some cases, older plants were converted by means of a by-pass shaft. Since then the problem seems to have been solved even if the scum itself cannot be avoided [9]. Total solid content of influent and gas production of the plant is assumed to be equivalent Deenbandhu plants.

This is the digester type that has been constructed in Fiji since 1997.
3.2.7 The Nepalese Digester
A comprehensive quality standard and control system has been developed in Nepal to support the installation of over 150,000 fixed dome digesters from 1992 to 2005 which has directly benefited over 980,000 people. A plant suitable for a rural household costs US$300 (£167). Government subsidies have made the plants more affordable for households, bringing the cost down to $200, which can be recouped by savings in fuel costs within three years [9].

![Diagram of a biogas plant](image)

**Figure 7: The Nepalese biogas digester**

*Source: [9]*

Total solid content of influent and gas production of the plant is assumed to be equivalent to Deenbandhu plants.

3.3 High rate anaerobic reactors

3.3.1 Upflow Anaerobic Sludge Blanket (UASB) Reactor
This UASB design was developed in 1980 in the Netherlands. It is similar to the anaerobic filter in that it involves a high concentration of immobilized bacteria in the reactor. However, the UASB reactors contain no packing medium; instead, the methane forming bacteria are concentrated in the dense granules of sludge blanket which covers the lower part of the reactor. The feed liquid enters from the bottom of the reactor and biogas is produced while liquid flows up through the sludge blanket. Wastewater flows upwards through the blanket and is processed by the anaerobic micro-organisms. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants. The blanket begins to reach maturity at around 3 months [9]. Small sludge
granules begin to form whose surface area is covered in aggregations of bacteria. In the absence of any support matrix, the flow conditions create a selective environment in which only those micro-organisms, capable of attaching to each other, survive and proliferate. Eventually the aggregates form into dense compact bio-films referred to as "granules". For achieving the required sufficient contact between sludge and wastewater, the UASB-system relies on the agitation brought about by the natural gas production and on an even feed inlet distribution at the bottom of the reactor [9].

The primary use for UASB digesters is for the treatment of higher strength industrial wastewaters, but it can be used for lower strength municipal wastewater - especially in tropical areas where it is even possible to effectively process dilute water streams (3% TSC) [9], [9]. At temperatures exceeding 12°C, COD removal efficiency was around 60% and was not greatly influenced by temperature, loading rates, or HRT.

The primary use for UASB digesters is for the treatment of higher strength industrial wastewaters, but it can be used for lower strength municipal wastewater - especially in tropical areas where it is even possible to effectively process dilute water streams (3% TSC) [9], [9]. At temperatures exceeding 12°C, COD removal efficiency was around 60% and was not greatly influenced by temperature, loading rates, or HRT.

UASB technology usually requires constant monitoring when put into use to ensure that the sludge blanket is maintained, and not washed out (thereby losing the effect).

Performance: The blanketing of the sludge enables a dual solid and hydraulic (liquid) retention time in the digesters. Solids requiring a high degree of digestion can remain in the reactors for periods up to 90 days. Sugars dissolved in the liquid waste stream can be converted into gas quickly in the liquid phase which can exit the system in less than a day [9]. One gram of granular sludge organic matter (dry weight) can catalyze the conversion of 0.5 to 1.0 grams of COD per day to methane. In layman terms that means on a daily basis granular sludge can process its own body weight of wastewater substrate [9]. UASB digesters are quite effective in removing and stabilizing organic pollutants at liquid detention times as low as 4 hrs, i.e. a biochemical oxygen demand reduction up to 75-95% can be achieved, while an almost complete treatment can be accomplished by combining the method with a small aerobic lagoon [9].

Advantages of UASB digesters are:

- Increased gas production
- Easy sludge harvesting from the settling tank
• Reduced hydraulic retention time to one day, reduces the cost of the digester
• No need for pre-settling of solids with dilute influent (>3% TSC)
• Reduced solids retention time to 30 days

Disadvantages include:
• Additional expense to build a settling tank is required to after the digester to collect the suspended particles and harvest the sludge
• Heating is required if the digester is going to operate in climates below 12 degrees Celsius

3.3.1.1 **Vertical Fibreglass UASB Design**
Fibreglass design are used for unheated UASB digesters between 10m$^3$ and 30m$^3$ and are rigid enough to handle below ground storage as well as gas pressure. Typical equipment and installation costs are US$71 per m$^3$ for the digester and hydraulic pressure tanks and US$35/m$^3$ for the effluent settling tanks [25]. These digesters are suited to use in tropical climates.

![Figure 9: ZERI Fibreglass UASB Digester](image)

*Source: [9]*

3.3.1.2 **Concrete UASB Digester**
Concrete UASB digesters are typically used for sizes over 30m$^3$ when it becomes uneconomically to build the vertical fibreglass digesters as described above.
Costs are US$100 per 1 m$^3$ of digester volume [9].
3.3.2 Expanded Granular Sludge Bed Reactor

The expanded granular sludge bed (EGSB) reactor is a variant of the UASB concept [9]. The distinguishing feature is that a faster rate of upward-flow velocity is designed for the wastewater passing through the sludge bed. The increased flux permits partial expansion (fluidization) of the granular sludge bed, improving wastewater-sludge contact as well as enhancing segregation of small inactive suspended particle from the sludge bed. The increased flow velocity is either accomplished by utilizing tall reactors, or by incorporating an effluent recycle (or both). A scheme depicting the EGSB design concept is shown in Figure 12. The EGSB design is appropriate for low strength soluble wastewaters (less than 1 to 2 g soluble COD/l) or for wastewaters that contain inert or poorly biodegradable suspended particles which should not be allowed to accumulate in the sludge bed.
3.3.3 Anaerobic Baffled Reactor:
This reactor is a simple rectangular tank, with physical dimensions similar to a septic tank, and is divided into five or six equal compartments, by means of partitions from the roof and bottom of the tank. The liquid flow is alternately upward and downward between the partitions, and on its upward passage the waste flows through an anaerobic sludge blanket, of which there are five or six. Hence the waste is in intimate contact with active biomass, but due to the design, most of the biomass is retained in the reactor [9].

A retention time of 1 day at 35°C, obtained 80% removal efficiencies of COD of effluent with a TSC of g/l COD.
3.4 Flexible Plastic Digesters

3.4.1 Red Mud Plastic Digester

Figure 14: Red mud digester

The bag digester is essentially a long cylinder (length:diameter = 3:14) made of PVC, a Neoprene coated nylon fabric, or "red mud plastic" (RMP), a proprietary PVC, to which wastes from aluminium production are reported to be added. Integral with the bag are feed and outlet pipes and a gas pipe (see Figure 7.4). The feed pipe is arranged so that a maximum water pressure of approximately 40 cm is maintained in the bag [9]. The digester acts essentially as a plug flow (unmixed) reactor.

The Red-Mud Plastic (RMP) digesters cost 25-30 US$/m\(^3\) for the typical PVC fabrication [9]. These digesters have been discontinued. Flexible PVC contains the toxic and environmentally persistent DEHP plasticizers, a dangerous endocrine disrupting chemical which leaches out into atmosphere and effluent the liquid.

Figure 15: Bag-Red Mud (Taiwan, China) Digester

Source: [1]

The basic design originated in Taiwan, China, in the 1960s, due to problems experienced with brick and metal digesters. The original material used, a Neoprene coated nylon, was expensive and did not weather well. After 1974 the availability of RMP, an inexpensive PVC with a life expectancy of over 20 years lead to the extensive use of this RMP digesters especially in Central America [9].
Typical retention times in bag digesters, for swine waste, vary from 60 days at 15° - 20°C, to 20 days at 30° - 35°C. One advantage of the bag is that its walls are thin, so the digester contents can be heated easily if an external heat source, such as the sun, is available. The Chinese have found that average temperatures in bag digesters, compared with dome types, are 2° - 7°C higher. Hence specific yields can be from 50 - 300% higher in the bag (0.235 - 0.61 volumes of gas per volume of digester per day). And in Korea, specific yields varying from 0.14 in winter (8°C) to 0.7 in summer (32°C) for swine manure were obtained [29].

Over 50,000 RMP digesters of over 10 m$^3$ are operating in China [30].

3.4.2 Polyethylene Tube Digesters

The use of cheap polyethylene tube digesters is popular in Vietnam where over 27,000 were installed between 1990 and 2002 [9], [9]. The digesters are typically made out of 10meters of double skinned 200-250micron thick 1.5 meter diameter clear polyethylene tube laid in a trench.

Figure 16: Typical polyethylene tube digester

Source: [34]

Polyethylene tube digesters cost typically (5 US$/m$^3$) which includes the cost of gas storage, piping safety valve and a cooker and have a life span of up to 10 years.

Figure 17: Typical Flexible Plastic Tube Digester configuration

Source: [35]
Maintenance: After three years, more than 40% of the biodigester plants had experienced some basic maintenance problems, especially with the plastic tubes. Most (40%) of the tube problems were related to excessive exposure to the sun which could be remedied with the construction of a roof. An interesting observation was that in 70% of the time the farmers could correct the problems by themselves, and only in 30% of the cases did they need help from technicians. Repairs were mainly simple and farmers could teach each other. The first farmers who had digesters installed more than 2 years ago needed help from technicians, while farmers who had installed their digesters within the last year could resolve their problems by themselves. Replacing a tube typically takes a few hours and costs $17 in materials [35].

Daily Maintenance: In order to optimize digestion and gas production, it is recommended to inoculate the influent with effluent on a daily basis. Biogas production is not possible without a sufficient quantity of biogas microbes. These are often low in number in fresh material. Taking some of the effluent (10 to 30% of daily input) and putting it back into the digester is a way of inoculating the fresh manure with the active microbial flora. This inoculation of fresh manure can increase gas production up to 30% and is very important in a plug-flow type digester as there is almost no mixing between old and fresh slurry [35].

Gas Production per digester volume is 0.36 m³/m³ per day based on the recommended TSC of 0.5% and a gas production of 150 l per Kg dry mass and an optimal hydraulic retention time = 20 days [35].

3.5 The Plug-Flow Digester

The plug flow digester, while similar to the bag reactor and tube reactors, is constructed of different materials and classified separately. A typical plug flow reactor consists of a trench lined with either concrete or an impermeable membrane. The trench length has to be considerably greater than the width and depth lined with concrete or an impermeable membrane. The reactor is covered with either a flexible cover gas holder anchored to the ground, concrete, or galvanized iron (GI) top.

To ensure true plug flow conditions, the length has to be considerably greater than the width and depth. The reactor is covered with either a flexible cover gas holder, anchored to the ground, or with a concrete or galvanized iron top. In the latter type, a gas storage vessel is required. The inlet and outlet to the reactor are at opposite ends, and feeding is carried out ‘semi-continuously’, with the feed displacing an equal amount of effluent at the other end.

The first documented use of this type of reactor was in South Africa in 1957 [39], where it was insulated and heated to 35°C. Specific yields (vol. gas/volt digester/day) of 1 - 1.5 were obtained, with retention times of 40 days and loading rates of 3.4 kg total solids per m³/day.
At 20°C the plug flow reactor yields about 0.42 volumes of gas per volume of digester per day. At typical lower loading rates (9% versus 12.9% total solids) this figure would decrease to around 0.29. [40]

### 3.6 Anaerobic Lagoons

Anaerobic lagoons are used to dispose of large volumes of animal waste, particularly that of cows and pigs. Areas with cold winters are inappropriate for anaerobic lagoons because the activity of the micro-organisms is highly dependent on temperature. It is critical to have the proper size for the lagoon, with volume being more important than surface area. A minimum of two meters is necessary for anaerobic conditions, but the depth should not exceed 6 meters. Sometimes a secondary lagoon is used to accept wastes while the primary lagoon is undergoing maintenance or for other purposes.

![Figure 19: A photo of the anaerobic lagoon at the Cal Poly Dairy taken in 2003](source: [41])

If the anaerobic lagoon system is being used for energy production, the primary lagoon has a cover floating on the surface of the water. The cover captures the biogas produced by anaerobic bacteria. The biogas produced by anaerobic lagoons is 50 to 75% methane, with carbon dioxide making up most of the rest. The gas is usually used to produce electricity using a microturbine or reciprocating engine, but it can also be used for water or space heating. The gas usually undergoes pre-treatment, particularly dehydration, prior to combustion. Sometimes the carbon dioxide, which is incombustible, is also removed.

### 3.7 Batch and Dry Fermentation

This is the simplest of all the processes. The operation involves merely charging an airtight reactor with the substrate, a seed inoculum, and in some cases a chemical (regularly a base) to maintain almost neutral pH. The reactor is then sealed, and fermentation is allowed to proceed for 30 - 180 days, depending on ambient temperature. During this period, the daily gas production builds up to a maximum, and then declines. This fermentation can be conducted at "normal" solids content (6 - 10%) or at high concentrations (>20%), which is then known as "dry" fermentation [1].
"Dry" fermentation can proceed at total solids concentrations up to 32%. At a temperature of 35°C a mix of grass and manure at 25% total solids, using a manure inoculum of 30% by weight, can achieve gas productions of 0.79 m³/m³/day over 60 days. This increases to around 3.0 m³/m³/day at 55°C [42]. This reactor could run for the duration of a year so the unloading and use of the digested slurry can be planned in advance.
4. Fiji digester design

This section provides a basic guideline for the planning and construction of small to medium sized brick Fixed Dome Biogas Digesters. The design to be adopted by the NBP fulfills the following criteria:

- reliable, durable and user-friendly: the digesters should have an estimated lifetime of over 20 years with a minimum of maintenance;
- replicable: with local available material and local skilled manpower, the digesters must be able to be constructed nationwide;
- adapted to local conditions (climatic and soil conditions, quality and quantity of feeding material, etc.);
- the cost of the digesters should be as low as possible without affecting the durability.

The fixed dome digester that will be used in the NBP comprises a closed digester with a fixed, non-moving gas space and a compensating tank. The gas is stored in the upper part of the digester. Gas production increases the pressure in the gas space of the digester and pushes the slurry into the compensating tank. When the gas is extracted, a proportional amount of the slurry flows back into the digester.

The main advantages are as follows:

- a long life span (no moving and steel parts);
- its total cost is less than that of a floating gasholder plant;
- can be built below ground level: saving space and easier to insulate and protect the digester;
- provides opportunities for skilled local employment;
- the long-lasting technology enables finance institutions to offer loans with sufficient recovery time;
- the technology will have less failure and risk resulting in high consumer confidence.

The disadvantages are as follows:

- they require more skilled masons in order to keep the plant gastight with risk of gas losses if the construction is not properly done;
- transport of building materials to scattered Fijian residences significantly affects the prices of biogas plants;
- gas pressure fluctuates substantially depending on the volume of gas stored and the height of the slurry level in the outlet chamber.

For a description of different household-scale digesters, and a comparison of their relative advantages and disadvantages, please refer to Section 3.

4.1 Description of the digester

Initially only one design of fixed dome digester will be approved, be it in different specified sizes and materials (bricks or stones according to prices and availability). For this national model, guidelines and construction manuals, bills of quantities, equipment requirements, etc. have been developed. Other proven designs can be admitted later on if
there would be a demand for a new design and if all conditions for the smooth implementation of the programme are in place.

In this first phase, only 4, 6, 8, 15 and 20 m$^3$ will be constructed (see Figure 21). Farmers requiring larger systems are considered wealthy enough to decide for a biogas plant without a subsidy incentive.

The experience with domestic biogas programmes in other countries has shown that the establishment of quality standards and their enforcement is vital for the success of the programme. All involved and in particular the users, must have full confidence in the technology and the programme in order to let the commercial approach work. Together with the partners involved in the construction work, the quality standards will be developed as well as the methods to control and enforce these standards.

In addition to these criteria, the following points should be kept in mind when deciding on a site for biogas plant construction:

- convenience is key, to make plant operation easy and to avoid wastage of raw material, the plant must be as close as possible to the cattle shed and water source. Ideally, the concrete slab from the stable should be connected directly to the tank;
- if longer gas-pipes are used, the cost and the risk of gas leakage will increase. The main valve has to be opened and closed before and after use. To eliminate the above problems, the plant should be as close as possible to the point of use (maximum 20 metres away);

Figure 21: Drawing of the 4 m$^3$ digester

*Source: AGAMA Energy (Pty) Ltd*
• the edge of the foundation of the plant should be at least two meters away from the house or any other building to avoid risk of damages;

• the plant should be at least 10 meters away from the well or any other underground water sources to protect water from pollution.

If the concerned masons and plumbers strictly follow these instructions during construction, the complete plant will be of high quality. Hence, the plant owner will benefit ultimately from the investment and positive return will be achieved as per the expectations. This again will persuade his relatives and neighbours to install a biogas plant, while a poorly constructed plant will do harm to the reputation of biogas technology.

Given the distribution figures of the national herd over the rural households, the gathering practices of dung and the climate, $6 \text{ m}^3$ will presumably be the most common plant size to be constructed over the first years. With a feeding of 20 kg/day, such a plant will produce a minimum of 1.5 m$^3$ gas per day.

### 4.2 Feeding materials and loading rates

The target group (market) for the NBP consists of households/farmers who have a minimum of 20 kg of animal, sewage and organic waste at their disposal on a daily basis. This amounts to the daily dung production of one to two average size, stall-fed head of cattle or four adult pigs. Table 3 indicates the expected ‘normal’ size of digesters in the initial stage of the NBP, and the associated feedstocks (based on a 45 day retention time).

#### Table 3: Digester size as a function of the available feedstocks

<table>
<thead>
<tr>
<th>Size of digester (m$^3$)</th>
<th>Approximate alternative feeding conditions (maximum)</th>
<th>Expected minimum gas yield (m$^3$/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of cows, zero-grazing</td>
<td>No. of cows, ranging</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>1 - 2</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>20</td>
</tr>
</tbody>
</table>

### 4.3 Technical specifications

#### 4.3.1 Planning

A fixed dome digester is relatively simple in design and construction. However, because biogas digesters can be built within many different environments, local conditions will differ. Site specific plans, method statements and risk assessments should be drawn up, assessed and agreed upon by all involved in managing the project. Before work commences this information must be communicated to and agreed upon by the workers.

A plan (ideally with ground contours) must be drawn up showing the proposed site on the property, existing structures and proposed system components i.e. the digester, waste ducting inlet and outlet routes, reed bed (if installed) and gas line routes.

#### 4.3.2 Siting

The digester including inlet and outlet ducting and gas piping must be constructed underground. The system is then out of site, protected from physical damage, ground surface space is not occupied and gravity flow from the source is easier. Because a dome
is stable by virtue of the whole structure being in compression, it is also for this reason better that it be underground. There should be a minimum of 300 mm of compacted soil above the top of the dome of the digester.

A site evaluation should be carried out. This includes the following assessment:

a) Soil conditions - these should be assessed and deemed fit for purpose by a technical specialist. The type of soil (sand, clay, rock) should be determined. Ideally one is looking for soil conditions which would make the excavations easy yet provide a stable base for the digester structure. This would typically be sand or clayey sand.

b) Slope of land - because the effluent water coming into the system would typically be gravity-fed, one is looking for an area which has a slope. If the site is too flat the pipe must be laid deep (in order to achieve the minimal falls). On the other hand, if the slope of the land is too much, the construction will be difficult. Ideally the slope should be between 1% and 5%. One must also be mindful that the outflow must flow away from the digester so there must be a fall on the downhill side as well. A level survey must be done so that all these factors may be taken into account.

c) Water table - the digester should be built in an area where, should there be some leakage, pollution of the groundwater does not take place. The presence of ground water would also make construction difficult. The plant should be at least 10 metres away from a well or any other under ground water sources to protect water from pollution, in the event of a leak below ground level.

d) Existing structures - system components should be sited to least affect existing services and structures.

e) Proximity to source of waste - the digester should be positioned downhill and close to its sources of waste. This will aid gravity flow and minimize the amount of ducting and piping in the case of sewage, while a shorter distance to the kitchen (food wastes) and animal pens (manure) will limit the amount of effort in transporting these feedstocks to the digester. The outlet side of the digester must also be considered. The effluent leaving the digester is largely solids-free so the pipes can be laid at a flatter slope (minimum 0.5%). It is thus more economical to site the digester closer to the input source than to the post-treatment area (reed bed or wetlands).

f) Proximity to gas usage - the gas pipes are expensive and the longer the pipe the more the risk of leakage. Therefore the plant should be as close as possible to the point of use so that the above problems are eliminated. However, the rule of thumb is that the digester ‘belongs’ to the animal pens and not the kitchen, since the bulk of wastes (resources, and beneficial outputs) arise from there. If no animal wastes are involved, then the digester must be placed as near to the kitchen as possible.

g) Access - for maintenance purposes one would prefer to site the digester close to a road. However, care must be taken that traffic cannot drive over the digester.

h) Climate - ideally the system should be installed in an area which is hot and dry (rather than cold and wet).

i) Proximity to bushes and trees - the system must be kept a safe distance away from potential veld fires. Also, roots from large trees may in time interfere with the working of the system. An area of 10m should therefore be cleared around the system.

4.3.3 Selecting the correct size

In order to determine which of the biogas digesters should be built, an estimate should be made of the volume of effluent will flow into the tank. It is important to size the digester correctly: too big will be overly expensive and too small will not work effectively.
The sizing guideline presented in should be used as a basis for implementing biogas projects. As experience is gained, the sizes can be altered slightly to cater for particular site requirements. There are two key approaches:

- For sanitation (often lots of water)
- For agricultural wastes (much less water)

In practice the designer performs two calculations: one based on the daily flow rate of water, the other on the organic feedstock volumes. For sanitation projects the recommended guideline is 5 days HRT (with a minimum of 3 days HRT) while for solid feedstocks the recommended guideline (for Fiji) is 45 days SRT. Refer to Table 3 for a sizing chart.

### 4.3.4 Materials determination

A list of materials required for the system should be drawn up. Depending on availability, an additional quantity should be ordered to allow for waste. Similarly the materials should be priced and a budget drawn up so that enough money can be set aside for this. Besides the materials, labour and management costs must also be factored in.

#### 4.3.4.1 Cement

The cement to be used has to be high quality Portland cement. It must be fresh, without lumps and stored in a dry place under cover. Bags of cement should never be stacked directly on the floor or against the walls but wooden planks should be placed on the floor to protect cement from dampness.

#### 4.3.4.2 Sand

Sand for construction purpose must be clean. Dirty sand has a very negative effect on the strength of the structure. If the sand contains 3% or more impurities, it must be washed. (The quantity of impurities especially the mud in the sand can be determined by a simple ‘bottle test’. For this test, small quantity of sand is put in the bottle. After this, water is poured in and the bottle is stirred vigorously. The bottle is than left stationary to allow the sand to settle down. The particles of sand are heavier than that of mud so it settles down quickly. After 20-25 minutes, the layers of mud versus sand inside the bottle are measured.) Course and granular sand can be used for concreting work but fine sand will be better for plastering work.

#### 4.3.4.3 Stone

Stone for the concrete mix should be 13 - 20mm in size. Furthermore, the stone must be clean. If it is dirty, it should be washed with clean water.

#### 4.3.4.4 Water

Water is mainly used for preparing the mortar for masonry work, concreting work and plastering. It is also used to soak bricks/stones before using them. Besides these, water is also used for washing sand and aggregates. Water to be used must clean.

#### 4.3.4.5 Bricks

Bricks must be of the best quality available locally and with a compressive strength of at least 14MPa. When hitting two bricks together, the sound must be clear. They must be well baked and regular in shape. Before use, bricks must be soaked for few minutes in clean water. Such bricks will not soak moisture from the mortar afterwards.

#### 4.3.4.6 Concrete and mortar

1. The concrete mix should be: 1 part cement, 3 parts sand, 6 parts stone
2. The mortar mix should be: 1 part cement, 4 parts sand
3. The plaster mix should be: 1 part cement, 1 part lime, 6 parts sand. The finishing (punning) plaster mix should be: 1 part cement, 1 part lime, 4 parts fine sand.
4. If ready-mix concrete is to be used, a 20MPa mix must be specified.
4.3.4.7 Waterproofing
Water- and gas-proofing the dome should be done either by using a locally-available waterproofing paint or by using a heated mixture of oil and wax.

A two-coat application of acrylic paint: cement mixture can also be used:
- first coat 1.5 paint : 20 cement
- second coat 1 paint : 2 cement

A list of required plant and materials should be procured and made ready for delivery.

4.3.5 Labour requirements
Labour requirements should be assessed. The digester construction requires at least one bricklayer/plasterer with experience in building biogas digesters. Additional bricklayers and labour will be required relative to the size of the structure and time/budget constraints. The system installation and digester construction should be managed by a person with a background in construction technology.

The installation of the waste ducting leading into and out of the digester must be carried out by a qualified plumber who must test and certify his work. Similarly, the gas connections and gas pipeline must be done by a person suitably qualified for this.

4.3.6 Plant and equipment
Generally it should be possible to build the digester without any mechanical machinery and in fact one of the advantages of this technology is that it can create job opportunities. When the ground conditions are such that excavation equipment is required, this must be taken into account in terms of cost and availability.

4.3.7 Jointing and bedding of pipework
It is important that drainage leading into the digester is installed correctly. If incoming material feeding a digester or reedbed is not what the system has been designed for the system will fail.

a) Storm- or rainwater should not lead into the digester because it dilutes the sewage and makes the digester ineffective and unpredictable.

b) Pipes should be installed to specified gradients. If the fall is not steep enough solid material will get stuck and cause a blockage. The pipe should have a minimum fall of 1:60 and a maximum fall of 1:5. If the pipe fall is more than 1:10, concrete anchor blocks should be provided every third pipe. Where the pipe changes direction, rodding eyes and thrust blocks should be provided.

c) Broken or incorrectly jointed pipes could result in ground water or organic root matter entering the pipe.

d) For domestic-type underground piping installations there is little risk of injury. For larger installations where deep trenches and heavy machinery is required a risk assessment must be undertaken.

e) The installation of pipework should be carried out by an experienced plumber or other person. On completion the pipework should be pressure-tested in an approved method. The installation should only be accepted through proof of positive test results.

f) The local authority or an expert should be consulted to establish the approved method of bedding and backfilling.

g) The trench should ideally be opened up immediately before pipe laying and it should be backfilled as soon as possible after the pipe work is installed.

h) The bottom of the excavated trench should be free from any protruding hard spots caused by tree roots, rocks or similar objects.
i) The bottom of the trench should be excavated to below the required level and brought back to level with selected stable material. Where unstable ground conditions occur, it should be over-excavated and backfilled with a mixture of sand, gravel and crushed stone.

j) Where pipes are to be laid in fill, at or above natural ground level, deposit the fill and compact it to a height of 1m above the proposed level at the top of the pipe. Then cut a trench for the pipe in the fill and lay it in the manner described for laying pipes below ground.

k) Careless bedding and backfilling can result in the collapse of a pipe.

l) The sketch below shows a typical section through a pipe trench, where
   i) Bedding material is ideally 9.5mm granular broken stone or gravel.
   ii) The cradle is the bedding zone in which material is placed firmly and without voids under and up the sides of the pipe in a manner that the pipe is not able to deflect. The base of the pipe should be uniformly supported by this compacted bed.
   iii) The blanket is the bedding zone in which material is placed and hand compacted from the top of the cradle up the sides and over the top of the pipe to the underside of the backfill.
   iv) The backfill or main fill is the remainder of the material placed and compacted in uniform layers. Mechanical compaction should not take place until at least 600mm of material has been placed over the top of the pipe. Excavated material may be used for fill provided it contains little or no organic matter, is free from stone exceeding 150mm and can be compacted so as to avoid significant settlement.

m) Where a pipe runs under an area carrying heavy traffic it should buried to a minimum depth of 1 meter above the top of the pipe. If this in not possible, either an approved heavier walled pipe should be used or the pipe should be sleeved in or positioned under an approved rigid material.
n) There are various ways to join different types of piping or ducting. It is important to join according to the manufacturer's instructions. If an adaptation needs to be made from one material to the other, manufacturer's adaptors need to be used.

o) If the pipe needs to be cut, it should be cut square to its axis and chamfered at the end.

p) An as-built survey of the pipeline’s direction and depth needs to be carried out and kept for record as well as maintenance and operations purposes.

4.4 **Sequence of work**

a) Exclusion zones must be set up and vehicular routes identified.

b) The location of the digester excavation and pipeline routes must be set out and marked.

c) Materials for the construction of the digester should be delivered. Sand, stone and bricks should be positioned close to the digester location for ease of building but not close enough to be a hazard to operations. Cement should be stored under cover and not exposed to moisture.

d) Levels should be set by a competent person.

e) The hole for the digester can then be excavated. This could be done by hand or by a mechanical digger. Depending on the soil conditions and stability, the sides can either be banked back at 45° degrees or where deemed necessary sheeted or shored to prevent collapse.

f) If there is a potential for ground or surface water to gather within the excavation a dewatering system needs to be installed. A simple way of doing this is to create a sump in the corner of or adjacent to the excavated hole and pump the water from there (or scoop out with buckets).

g) Once the bulk excavation is complete levels must be set for the top of the slab and excavation trimming needs to be done to ensure that the slab is of design thickness and sufficient size throughout. It is normal practice for a working platform to be cast before the main base is started. This is a 50mm low-strength concrete ‘blinding layer’ which makes it easy to walk on and place the reinforcing steel.

h) The foundation steel must then be placed correctly, ensuring that proper thickness of concrete under the steel is maintained by placing the steel on spacer blocks. These spacer blocks can be either pre-cast concrete blocks with wires to fix onto the steel or manufactured plastic type.

i) The concrete foundation can now be cast in one of three ways. An assessment must be made to determine which is most economical:

   i  by ready-mix mobile vehicle

   ii  machine mixed on site

   iii  Hand mixed on site.

   It is important to check that the correct strength concrete is being placed (For (i), check the driver’s ticket. For (ii) + (iii), use a mix design). The concrete should either be chuted or dumped, not dropped.

   The base is the founding support for the rest of the structure: it is therefore important to use the correct strength and thickness concrete.

j) Once the concrete is hard the digester and adjacent manholes can be set out on the slab and bricklaying can commence. The bricklayer will determine the centre point of the digester, and adopt a system of laying bricks with counterweights as he progresses his dome curve. It is important to use specified bricks, mortar and
plaster, as these determine the strength and porosity of the structure. Similarly
the manholes must be built up as the dome progresses.

Simultaneously to construction of the dome brickwork the building is reinforced
by wire mesh which is placed outside of the structure, embedded into an outside
plaster. Chicken wire is cut in metre-long strips, with these strips sectioned off
into their ends with an angle of 93° (87° respectively) so that the pieces form
trapezoid shapes. These pieces are placed behind the sphere so that the longer
ends are forming the circle of the foundation, whereas the shorter sides will be
joined and placed at the higher brick wall section. The pieces are tied together on
the short ends with binding wire or loose ends wire.

As soon as the wire layer is tightly spanning around the building, including the
inlet and outlet, the outside is plastered with a mixture of 1 cement:3 sand.

At the same time the cylindrical inlet and outlet structures receive a layer of wire
mesh to prevent cracking. The inlet and outlet have to be well joined with the
hemispherical building. They rise together at the same speed, and when they
reach 50 cm in height above the join with the dome the first layer of wire mesh is
placed behind the brickwork and the outside plaster is applied.

k) The gas pipe outlet must now be fixed to the top of the dome.

l) The excavation is back-filled as the building progresses. The material used should
be sand or clayey sand, but should not contain any large stones. The backfilling
should be done in evenly distributed layers, usually in depths of around 0.5
metres at a time, and lightly but well compacted so as not to exert uneven
pressure on the structure. Care must be taken that this layer-wise external
plastering does not allow for cracks to develop.

m) Internal plastering can take place once the dome is complete. The primary
purpose of the plaster is to make the dome watertight, both to prevent water and
gas leaking out of the dome (the inside plaster) as well as preventing ground-
water from entering the system (the external plaster). The proper functioning of
the plant is very dependent on the gas-tightness of the dome and great care
should be taken to ensure that especially the internal plasterwork is done
properly. On both sides initial plastering should extend from the base slab into
the concrete/brick corner. It is better to plaster the dome internally in a continual
operation.

n) After the plaster on the inside has been completed, it should be made gas-tight
with a waterproofing paint or a heated mixture of wax and oil.

o) Fit covers over the three manholes. The covers must be heavy enough that small
children cannot lift them. The gas outlet manhole should preferably have a
lockable cast iron cover.

p) The gas pipe is then fixed to the digester gas outlet and the gas line is installed
and fixed to the gas utilization outlet.

q) The expansion chamber must be built and the inlet pipework connected to the
inlet manhole.

r) An as-built drawing should then be made. All components, particularly the ones
that are underground and hidden should be marked on a plan and kept for record
purposes and to help with the system’s maintenance.

4.4.1 Gas installation
Methane is the principle component of natural gas or biogas. A biogas digester produces
methane and carbon dioxide which make up 2/3 and 1/3 of total gas produced,
respectively. Small amounts of nitrogen, hydrogen and hydrogen sulphide also occur. In
principal biogas can be used like any other gaseous fuel. It can be used for lighting in
lamps, in combustion engines to generate power, to drive gas turbines or in burners for
cooking. If biogas is burnt it eliminates harmful greenhouse gases and also provides
energy. 1m³ of biogas will provide a cooking time of at least 2 hours, or 1.5kwh electrical output.

Gas is generated by bacteria acting upon waste matter within the digester. The gas is collected within the dome and stored in the dome until ready for use. The fixed dome plant follows the principal of displaced liquid substrate through gas pressure. Gas pressure is created by the difference in liquid level between the inside and outside of the closed vessel. The dome outlet therefore acts as a safety valve (see risk assessment).

In many parts of the world biogas technology is in its infancy; therefore registered biogas installers do not exist. Where registered installers do exist they must be used for the installation. Where a registered installer does not exist, either a LPG (liquefied petroleum gas) registered installer should be used or the installation should be signed off by an appropriate engineer. Before commissioning the installation should be inspected, tested and approved by the installer.

4.4.1.1 Installation of the gas line
Biogas always contains a certain amount of water vapour which condenses to water when gas cools down. It is therefore important that the pipe does not sag as this may create a water trap and block the gas flow.

a) Approved ridged ¾” galvanized steel pipes must be used throughout. The pipe size can be reduced to ½” at the house or site of gas use.

b) Where possible, pipes must be laid in a continuous slope towards the drain point, as the gas contains condensation water. In case a continual slope cannot be established, the piping system should be equipped with a water trap at the low point(s) of the piping system.

c) Pipes must be laid on an even compacted bed of sand or small stone (10mm). They should not be laid in a trench with large stone or tree roots that will dent them.

d) Pipe joints are to be done as per manufacturer’s recommendations. Seal the joints with tape, hemp or grease to prevent leaks as well as corrosion.

e) Each section of the piping system has to be pressure tested. For this purpose a pressure test unit must be used. If a leak is detected at 10 kPa pressure then the leak must be identified and repaired.

f) To prevent restrictions of gas flow the number of pipe fittings should be kept to a minimum. Bends should be used to avoid sharp changes of direction.

g) Pipes should be handled with care so as not to damage the outside coating which will accelerate corrosion.

h) Buried pipelines should be installed to a depth of at least 500mm and trenches back-filled by approved means. Pipelines that are running under vehicle trafficked areas should be installed at a minimum depth of 800mm and protected with well compacted fill (mechanical for the last 300mm). Chevron warning tape should be placed half-way between the pipe and the surface (see risk assessment).

i) If the pipe is cut the burrs must be removed and any dust, dirt and scale inside the pipe and fittings should be cleaned out before assembly. Care must be taken to ensure that the bore of the pipe is not restricted by the entry of any material.

j) Copper pipe should be used be use from the main distribution pipe to the proximity of the burner (flexible hose can be used provided it is not longer than 2meters). A gas pressure meter (manometer) could be installed near the point of consumption where it is difficult to see the amount of gas available.

k) A water trap to collect condensed water vapour which develops in the pipes can also be installed at this point.

l) An approved flexible hose or tubing from the copper pipe to the burner should be used. This allows the burner to be moved without disconnecting the pipe. A flexible shower hose is often a good solution.
4.4.1.2 Connecting to the gas burner

a) The appliance must be installed on a firm and level base. The support for the appliance should be wide enough to prevent the appliance from slipping off the support.

b) When siting the appliance, due regard should be paid to the convenience of use, protection from draughts and damage and to the layout of the piping system.

c) Pipe runs should be as neat and as short as possible (not longer than 2 metres).

d) There should be no undue strain on the pipe work and it should be kept well below the level of the open burner.

e) The pipe should only supply one appliance i.e. there should be no T-junctions along its length.

f) Hose clamps should be used on flexible pipe connections.

g) Shut off valves should at all times be accessible.

h) Appliances shall not be installed in small confined spaces that are poorly ventilated as the burner requires an unrestricted supply of fresh air. Appliances shall be so sited in a room that there is no danger that they could set fire to furnishings (e.g. under a shelf or adjacent to curtains).

i) Gas piping should be at least 150mm away from electric cable and should be firmly supported with purpose-made clips or hangers.

4.4.1.3 Provision for ventilation

Incorrect installations or misuse of gas burning appliances within a building can give rise to hazardous conditions such as a build-up of unburnt gas and the depletion of oxygen. The provision of ventilation is therefore of vital importance. Biogas is lighter than air and therefore ventilation needs to be at ceiling level.

4.4.1.4 Modifying the LPG appliance

Purpose-built biogas burners are available in certain parts of the world. Where they are not available LPG (liquefied petroleum gas) appliances need to be modified. It is important that the modification is carried out correctly and by an appropriate person.

a) Biogas needs a certain amount of air to burn: on average 1m³ of gas requires 5.7m³ of air for complete combustion. This is only one quarter of what LPG would need.

b) LPG burners have smaller jets; consequently the relative air intake compared to biogas burners is greater.

c) The air intake that is needed for combustion is regulated by the difference of jet diameter to mixing pipe diameter. For open burners, which draw primary air at the jet and some secondary air at the flame port, the ratio between jet diameter and mixing pipe diameter may be taken as 1:6.

d) When converting LPG equipment to biogas, the jet must be widened, to say 1/6 of the diameter of the mixing pipe of the burner.

4.4.2 Risk assessment

4.4.2.1 Building works

For any major building operation there should be a documented risk assessment. This assessment should be communicated to and acknowledged by all who are involved in the project. As much as possible should be done to avoid accidents which can be ugly as well as costly.

The risk assessment outlined below is applicable to the rural environment. There will be many more factors to consider in a built-up environment and therefore a more in-depth assessment will need to be done.
Table 4 outlines the hazards and the measures to be taken for their control.

**Table 4: Risk assessment for building works**

<table>
<thead>
<tr>
<th>HAZARD</th>
<th>CONTROL MEASURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 GENERAL</strong></td>
<td></td>
</tr>
<tr>
<td>a Site vehicles colliding with third parties</td>
<td>3rd parties to be notified of site works</td>
</tr>
<tr>
<td></td>
<td>Signage to be used.</td>
</tr>
<tr>
<td></td>
<td>Designated plant/vehicular routes</td>
</tr>
<tr>
<td></td>
<td>Licensed/certified drivers to be used.</td>
</tr>
<tr>
<td>b 3rd parties on site.</td>
<td>Exclusion zones to be established where necessary.</td>
</tr>
<tr>
<td></td>
<td>Barriers to be setup around deep excavations (exceeding 1.5m).</td>
</tr>
<tr>
<td></td>
<td>Manhole covers (or temporary covers) to be positioned (a lockable cover must be fitted to the gas outlet manhole).</td>
</tr>
<tr>
<td>d Vehicles/plant colliding on site.</td>
<td>Designated routes.</td>
</tr>
<tr>
<td></td>
<td>Licensed/certified drivers to be used.</td>
</tr>
<tr>
<td></td>
<td>A banksman to be used when driver’s vision is impaired</td>
</tr>
<tr>
<td>e Tripping over objects</td>
<td>Ensure good housekeeping/site cleanliness</td>
</tr>
<tr>
<td>f Falling or dropping objects.</td>
<td>Work boots to be worn (preferably steel capped)</td>
</tr>
<tr>
<td><strong>2 EXCAVATIONS</strong></td>
<td></td>
</tr>
<tr>
<td>a Workers falling into excavations.</td>
<td>Barriers to be set up around deep excavations (exceeding 1.5m).</td>
</tr>
<tr>
<td>b Access into excavations</td>
<td>Ramped or stepped access</td>
</tr>
<tr>
<td></td>
<td>Properly sized (should protrude 1m above the platform) and fixed ladders (top and bottom).</td>
</tr>
<tr>
<td>c Collapse of excavated sides</td>
<td>Sides to be battered back at 45degrees</td>
</tr>
<tr>
<td></td>
<td>Sheeting or shoring installed if deemed necessary.</td>
</tr>
<tr>
<td>d Digger falling into excavations.</td>
<td>Use a certified driver.</td>
</tr>
<tr>
<td></td>
<td>Use a banksman where driver’s vision is impaired</td>
</tr>
<tr>
<td>e Exposure to hazardous gasses in deep excavations</td>
<td>Monitor personnel</td>
</tr>
<tr>
<td></td>
<td>Create airflow</td>
</tr>
<tr>
<td>f Objects falling into excavations</td>
<td>Keep objects away from the sides of excavations</td>
</tr>
<tr>
<td><strong>3 PLANT/POWER TOOL USE</strong></td>
<td></td>
</tr>
<tr>
<td>a Plant accidents.</td>
<td>Ensure operators are certified.</td>
</tr>
</tbody>
</table>
4.4.2.2 Gas installation and use
All details pertaining to the system shall be discussed with the user to ensure that he/she fully understands the details. Warning signals indicating a hazardous condition should be able to be detected by the user. Once the signals are triggered, the system should be checked and rectified by an appropriate person.

Table 5 outlines the hazards and the measures to be taken for their control.

<table>
<thead>
<tr>
<th>HAZARD</th>
<th>CONTROL MEASURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROUND SURFACE FIRES</strong></td>
<td></td>
</tr>
<tr>
<td>a Heat from the fire causing an explosion within the digester.</td>
<td>Provide a landscaped area of 10 metres around the digester.</td>
</tr>
<tr>
<td>b Excessive heat melting the underground pipelines.</td>
<td>Install pipelines to specified depth</td>
</tr>
<tr>
<td>c Uncontrolled supply of gas from source to outlet within range of fire.</td>
<td>Ensure correct positioning of shut-off valves as well as free and full movement of the valves.</td>
</tr>
<tr>
<td><strong>EXCESS PRESSURE</strong></td>
<td></td>
</tr>
</tbody>
</table>
### Build-up of gases within the dome in excess of the required design pressure.

**Double check the riser to dome inlet and outlet levels and clear passage thereof during the construction process (the outlet acts as a pressure release valve).**

Ensure that only biodegradable matter is being fed into the digester and not matter that will cause a blockage.

### GAS LEAKS

#### a. Build-up of biogas within a building (exposure to toxic gas and oxygen depletion).

User to be made aware of the smell of biogas for the detection thereof.

- Check shut-off valves for corrosion or mechanical damage and ensures free and full range of movement.
- Check flexible tubing for signs rupture, cracking or perishing and replace if necessary.
- Check flexible tubing fittings and clamps
- Check free entry and circulation of air. Adequate ventilation must be built in such a way that it cannot be blocked.

#### b. Gas leaking through valves, joints and pipes

- Check flexible tubing for signs of ruptures, cracking or perishing and replace if necessary.
- Check valves for signs of corrosion or mechanical damage and ensure free and full range of movement.
- Check correct jointing of sub-surface and suspended pipework.
- Ensure sub-surface and suspended pipework is correctly supported
- Check pipework for signs of corrosion.

### DAMAGE TO INSTALLED PIPES

#### a. Damage to underground piping through hand or plant excavation

Install piping to specified depth.

Install chevron warning tape above the pipe line.

Ensure the user has a copy of the as-built survey which will indicate the position of the gas line.

### BUILDING FIRES

#### a. Fires within the building

Ensure that appliances are not sited near combustible material (e.g. under flammable shelving or close to curtains).

Ensure that the flexible tubing is below the flame.

Provide one or more dry powder extinguishers in a clearly visible location near the burner.

Locate piping at least 150mm away from electric cabling.
4.5 Drawings
The drawings of the 4 m$^3$ digester is presented in Annex A: Drawing of the 4 m$^3$ digester
5. Quality management

The primary criteria for managing the quality of the biogas plant and its ongoing successful functioning include

- Durability
- Reliability
- Affordability
- Methods of construction
- Methods of O&M
- Uniformity

The importance of and procedures for quality management cannot be underestimated. The success or otherwise of the NBP will to a large extent depend upon the degree to which a quality management culture is developed at every tier of the programme. Without a quality product the marketing and promotion of the technology becomes increasingly more difficult, while the costs of the product tend to rise over time due to repeated maintenance services having to be provided. One immediate outcome of this focus is the necessity to develop grading systems for biogas companies, using a performance index approach.

The following is a checklist that should be adhered to by supervisors confirming the quality of the installed product:

- An interview of users via a questionnaire or checklist must be properly completed.
- Check the selected size of plant based upon the quantity of water, manure and other feedstocks available. The HRT for the water should be a minimum of 5 days, while the manure/feedstocks should be available at approximately 5 kg per cubic metre.
- Check the selected site. It should be in a sunny area near the kitchen and cattle shed in appropriate distance from ground water sources, at least 2m far from any structures and at a distance where the tree roots will not affect the plant.
- Check the digester. The digester pit should be excavated to the desired depth. The radius of the dome wall should not deviate by ± 2 cm from the standard dimension. The backfill should be filled with a mix of aggregate, soil and water. The inside of the dome should be smoothly plastered with 1:3 cement sand mortar, and finished for gas tightness in the gas zone. The surface of the floor should be smooth.
- Check the inlet and toilet attachment. Even if a toilet is not installed at the time of building the digester, an inlet sewer pipe has to be installed nevertheless.
- Check the laying, jointing and protection of pipe
- Check the position of the water trap and drain pit, if installed.
6. Commissioning

Starting up the digester can be a process requiring patience. It can take up to several weeks for a digester to stabilize and they often need a little “nursing” along at first. The correct bacteria are normally present in the feed-stock and time is needed to build up the bacterial population numbers to full production levels, as well as to stabilise the digester pH, or ‘acid balance’.

For best performance the digester should initially be filled with cattle manure and water. If there is not enough manure conveniently available, the remaining volume can be filled with water. The correct filling level is to the bottom of the expansion canal, with the gas valve open. Once filled the gas valve can be closed. The manure will settle at the bottom of the digester and after a few days it will start producing gas. Initially the gas produced will be predominantly carbon dioxide (CO$_2$) which should be vented off. The production of methane gas (CH$_4$) will build up as the pH of the digester stabilises.

For safety reasons it is advisable to vent off all the gas initially produced as the methane mixed with air is highly explosive!

The digester must not be overloaded. During the gas build-up phase, small amounts of the routine feed stock must be fed to the digester and gradually increased to the full feed rate over a period of two to three weeks. Excessive feeding at start up can cause a scum to develop on the surface which will inhibit gas production.

The start of the routine feeding depends on the feeding material itself. Manure and faeces can enter the digester at full or nominal quantity from the outset. For the case of garden waste, grass, straw, citrus waste, etc the bacteria in the digester have to adapt to this feeding material. It is best therefore, to start with 1 bucket per day and increase to two/three buckets after a week.

The quality of the gas produced is an indication of the adaptation of the bacteria population to the feed stock. If the quality of the gas flame deteriorates it indicates that more CO$_2$ is being produced and the feeding should be stopped for a few days. After construction, the plant is loaded with a mixture of dung and water. For example, if cow dung is used, one part of water should be mixed to one part of fresh dung for achieving the desired consistency of the slurry. Depending upon the season and ambient temperature, it may take from one week to about 4 weeks for the production of combustible gas in the digester. Addition of effluent from operating plants have been found to reduce the gas generation time. The gas first generated has high CO$_2$ content and does not burn. Therefore, the initial gas volume needs to be vented to release excessive CO$_2$. Regular feeding of digester with recommended amount of input mixture has to be continued till the gas starts burning smoothly.

First hand knowledge on operation procedures of biogas plants is provided to the users by the masons at the time of plant construction (see Section 7). Following their instructions, the users should operate their plants for six months after which the biogas company organizes users’ training for the benefit of users of nearby areas. Women users are given priority in such training.

After the commissioning of the plant there should be a 3-year guarantee for the main components like the inlet, dome, digester and the outlet, and one year for pipes and appliances. Necessary after-sale service should also be provided for a period of three years.

The following is a checklist of commissioning activities to be undertaken:

- Check the gas pressure: The gas should have minimum pressure to burn effectively.
- Check the performance of gas stove, gas lamp, water drain, etc: The gas stove should burn with blue convergent flames giving hissing sound to have optimum calorific value of the gas. The gas lamp should burn without any problem.
must be no any gas leakage from the appliances. The water drain should be capable of flushing the condensed water.

- Check for gas leakage: There must be no gas leakage from pipe joints.
- Check for top filling over the dome: There must be a properly compacted top filling of soil to a depth of 40 cm over the dome.
- Check the feeding amount of dung and slurry thickness: The prescribed feeding rate has to be followed for efficient functioning of plant, in a liquid:dung ratio of 1:1. The slurry thickness can be tested with the use of a stick/pipe/rod being dipped into the outlet. For an agricultural digester the slurry should adhere to the stick /pipe/rod and the slurry should flow gradually when the stick /pipe/rod is kept vertical.
- Take measurements of the commissioned plant and check against the drawing.
- Analyze overall functioning and efficiency of the plant: The satisfaction, expectation, requirements of user and general condition of the plant should be assessed.
7. **Operations and Maintenance**

After the inspection of the plant and signing off acceptance of the installation, the farmer should be oriented on plant operation and maintenance and should be provided with the instruction booklet which deals in plant operation. Basic training is provided at this time, and various problems encountered during initial plant operation phase are discussed in the training. The training covers different aspects of plant operation including technical problems and their possible solutions, proper utilization of digested slurry, advantages and disadvantages of biogas plants, after-sale-services of the biogas companies and repayment of bank loan.

The following are the primary operations and maintenance aspects that require consideration and attention:

### 7.1 User training

Even the best constructed plant will not function properly if the operation (daily feeding, use of appliances) is not done according to the plant design's requirement. Therefore the biogas company has an obligation to properly inform the user on the proper operation and maintenance of the plant. This has to be done through on-site instruction by the mason or a company representative during the construction phase and through the issuing of an operation and maintenance booklet covering the commissioning of the plant.

After the user has gained at least six months experienced in operating the plant, further training is desirable.

During primary training the following points should be covered:

1. **Feedstocks**
   - Only prescribed raw materials should be used to feed the biogas plant
   - Improper feeding materials can have serious implications to bio-gas plant functioning
   - Liquid requirements for plant feeding
   - Waste management procedures

2. **Advantages of the biogas system**
   - Use of biogas slurry
   - Economic, social, environmental and health impacts of biogas
   - Use of biogas slurry properly can help in reducing the amount of chemical fertiliser and safeguard the soil fertility
   - Biogas plant does not have major disadvantages.

3. **The functioning of the various components of the biogas plant must be explained**
   - Evolution of the biogas plant model
   - Different components of the biogas plant
   - The functioning of different components of the biogas plant.

4. **Utilising the gas needs to be explained**
   - Lighting the gas
   - Adjusting the air supply at the valve
   - Safety aspects
   - Gas availability and utilisation
• During the cold season, gas production is lower than normal. During this time the digester temperatures are too low for optimal gas production. Continue feeding the digester as normal, and it will recover on its own when the warm season starts again.

7.2 Troubleshooting

In addition to the above user training the user should be given a breakdown of troubleshooting procedures. These should include recording the history of the problem, and who to contact in case additional assistance is required.

Table 6: Common problems with biogas plants and remedies

<table>
<thead>
<tr>
<th>Defect</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Installation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cracking of digester Wall</td>
<td>Sinking of foundation or improper back filling</td>
<td>Repair and do proper back filling</td>
</tr>
<tr>
<td>Gas leakage</td>
<td>Improper sealing of joints</td>
<td>Check and repair</td>
</tr>
<tr>
<td>Accumulation of water in pipe lines</td>
<td>Improper installation of water trap</td>
<td>Check level and set the water trap at correct position. Drain water on a weekly basis.</td>
</tr>
<tr>
<td>Operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No gas after first filling of plant</td>
<td>Lack of time</td>
<td>It may take 3-4 weeks</td>
</tr>
<tr>
<td>Slurry level does not rise in outlet chamber even insufficient gas is coming</td>
<td>Insufficient amount of feeding</td>
<td>Add more feedstock and water</td>
</tr>
<tr>
<td>No gas in the stove but plenty in the plant</td>
<td>Leak in pipe Gas pipe blocked by water condensation</td>
<td>Check and correct Remove water from moisture trap.</td>
</tr>
<tr>
<td>Flame far from the burner</td>
<td>Pressure too high or deposition of carbon on the nozzle or air:gas ratio incorrect</td>
<td>Adjust gas valve and clean nozzle</td>
</tr>
<tr>
<td>Flame dies quickly</td>
<td>Insufficient pressure</td>
<td>Adjust gas outlet valve and clean nozzle</td>
</tr>
<tr>
<td>Unhygienic condition around biogas plant</td>
<td>Improper digestion Improper disposal of slurry</td>
<td>Add correct quantity of dung and water Regularise activities</td>
</tr>
</tbody>
</table>

Troubleshooting leakage in the gas line
• There should not be any gas leakage from pipe joints and appliances.
• Inspect for gas leaks along the piping system using a soap solution or shampoo, and fix it where you see bubbles.

• Never test for leaks in an enclosed space with any flame or burning match.

• To repair leaks:
  1. Leaking valves – replace the valve
  2. Leaking pipes – replace the broken portion

• Do not repair a pipe using strips of rubber tubing as these are only temporary and will not seal the pipe properly.

Troubleshooting the main gas valve and burner gas valve

• Gas should not leak through the gas valve
• The gas valve should be easily operated
• The gas line should not be blocked due to carbon clogging
• Ensure that the main gas valve is closed before removing the burner valve for repair.

Troubleshooting the gas burner

• The gas burner should burn with optimum efficiency
• The gas should not leak through gas stove
• The gas should not be blocked due to clogging of burner cap due to carbon or other dirt

Troubleshooting a gas lamp

• The gas lamp should operate in a trouble free manner.
• Gas should not leak from gas lamp
• The gas line should not be blocked due to carbon clogging.
• Ensure that the main gas valve is closed before removing the gas valve for repair.
• Parts and components of the gas lamp should be handled carefully.

Troubleshooting the water trap

• The water trap should function well for smooth plant and gas operation
• The water trap should be well protected in a drain pit

Cleaning an overflow blockage

• Ensure that digested slurry flows easily to the compost pit or reedbed through overflow opening.

Breaking the scum layer

• Digested slurry must flow easily from the plant
• The flow of gas must not be interrupted due to the presence of a scum layer
• Avoid falling inside the outlet chamber when clearing the scum layer
8. Bioslurry

8.1 Importance of bioslurry for crop production

Organic matter plays an important role because of its beneficial effects in supplying plant nutrients, enhancing the cation exchange capacity, improving soil aggregation, increasing water holding capacity of soils, stabilizing its humic content and increasing its water holding capacity. Organic soil amendments support biological activities and also control root pathogens. Biogas slurry has proved to be a high quality organic manure. Compared to FYM, digested slurry will have more nutrients, because in FYM, the nutrients are lost by volatilization (especially nitrogen) due to exposure to sun (heat) as well as by leaching. The farmer needs to use chemical fertilizer to increase his crop production. However, if only mineral fertilizers are continuously applied to the soil without adding organic manure, productivity of land will decline.

On the other hand, if only organic manure is added to the soil, desired increase in crop yield cannot be achieved. Fertility trials carried out in Nepal and elsewhere have revealed that optimum results can be achieved through the combined application of both chemical and organic fertilizers.

In countries where biogas technology is well developed, for instance in China, there is evidence which supports the fact that productivity of agricultural land can be increased to a remarkable extent with the use of slurry produced from biogas plants. In Fiji too, if properly managed, the biogas slurry could play a major role in supplementing the use of imported and expensive chemical fertilizers.

8.2 Characteristics of digested slurry

Only approximately 10 percent of the total nitrogen content in fresh dung is readily available for plant growth. A major portion of it has to first be biologically transformed in the soil and is only then gradually released for plant use. When fresh cow dung dries, approximately 30 to 50 percent of the nitrogen escapes within 10 days, while nitrogen escaping from digested slurry within the same period amounts to only 10 to 15 percent. Therefore, the value of slurry as fertilizer, if used directly in the field as it comes out of the plant, is higher than when it is used after being stored and dried.

The short term fertilizer value of dung is doubled after being anaerobically digested while the long term fertilizing effects are cut by half. Under tropical conditions such as in Fiji the short term value is of greater importance because rapid biological activities degrade even the slow degrading manure fraction in relatively short time.

Cattle dung contains about one percent total nitrogen. Nitrogen is considered particularly important because of its vital role in plant nutrition and growth. During anaerobic digestion, 25 to 30 percent organic matter is decomposed and hence the nitrogen percentage is raised to 1.3. Although no new nitrogen is formed during anaerobic digestion, 15 to 18 percent nitrogen is converted into ammonia (NH₄) whereas nitrogen in aerobically digested organic wastes (activated sludge, compost) is mostly in oxidized form (nitrate and nitrite).

Increasing evidence suggests that for many land and water plants, ammonium is more valuable as a nitrogen source than oxidized nitrogen in the soil. Ammonium is less likely to leach away and hence more apt to become fixed to exchange particles like clay and humus. Bioslurry has more free ammonia than available in composted manure.

As a result of anaerobic fermentation, about 30 to 40 percent of organic carbon present in the dung is decomposed as carbon dioxide and methane. The rest is retained as such and contains plant nutrients. When fully digested, the slurry from a biogas plant is odourless and does not attract insects or flies.

The organic fraction of slurry may contain up to 30-40 percent of lignin, undigested cellulose and lipid material, on a dry weight basis. The remainder consists of substances (mineral, salts, etc.) originally present in the raw materials but not subject to bacterial
decomposition. The amount of bacterial cell mass is low (less than 20 percent of the substrate is converted to cells). Therefore, there is less risk of creating odour and insect breeding problems.

Some of the major key features of biogas slurry can be summarized as follows:

- Biogas manure is ready in shortest possible time.
- There is minimum loss of nitrogen in biogas slurry due to anaerobic conditions in the plant.
- If night soil and cattle urine are added, availability of nitrogen and phosphorus in the biogas manure is increased.

8.3 Utilization of Digested Slurry

It has been observed that the use of digested slurry as manure improves soil fertility and increases crop yield. Data from field experiments suggest that the slurry should be applied at the rate of 10 tons/ha in irrigated areas and 5 tons/ha in dry farming. The manure can be used in conjunction with normal dose of chemical fertilizers. Such practice will help achieve better returns from fertilizers, minimize the loss of fertilizers from the soil and provide balanced nutrition to crops. Different methods of slurry applications are described this section.

8.3.1 Application of liquid bioslurry

The digested slurry can be directly applied in the field using a bucket or a pale. An alternative to this is to discharge the slurry into an irrigation canal. However, these methods of direct application have some limitations:

1. Firstly, not all farmers have irrigation facility throughout the year.
2. Secondly, in the cascade system of irrigation in which water is supplied from one field to another, slurry is not uniformly distributed in the fields.
3. Finally, since the digested slurry is in a liquid form, it is difficult to transport it to farms located far from the biogas plants.

The sludge and slurry can be applied to the crop or to the soil both as basal and top dressings. Whenever it is sprayed or applied to standing crop, it should be diluted with water at least at the ratio of 1:1. If it is not diluted, the high concentration of available ammonia and the soluble phosphorus contained in the slurry will produce a toxic effect on plant growth.

8.3.2 Application of dried bioslurry

The high water content of the slurry causes difficulties in transporting it to the farms. Even if it is applied wet in the field, tilling is difficult. Due to these difficulties, the farmers can dry the slurry before transporting it into the fields. When fresh slurry is dried, the available nitrogen, particularly ammonium, is lost by volatilization. Therefore, the time factor has to be considered while applying the slurry and in this regard, immediate use can be a way of optimizing the results.

8.3.3 Utilizing bioslurry for making compost

The above mentioned difficulties can be overcome by composting the slurry. If the slurry is composted by mixing it with various dry organic materials such as dry leaves, straw, etc., the following advantages can be realised: - The dry waste materials around the farm and homestead can be utilized. - One part of the slurry will be sufficient to compost about four parts of the plant materials. Thus, increased amount of compost will be available in the farm. - Water contained in the slurry will be absorbed by dry materials. Thus, the manure will be moist and pulverized. The pulverized manure can be easily transported to the fields. The ideal arrangement would be to dig three similar pits which may be filled in turn. The size of these pits should be such that by the time the third one is filled, the first one is dry enough to transport the compost to the field.
### Table 7: Nutrients available in bioslurry and manures

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Composted Manure</th>
<th>Farm Yard Manure</th>
<th>Digested Slurry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>0.5 to 1.5</td>
<td>1.0</td>
<td>0.5 to 1.0</td>
</tr>
<tr>
<td>Phosphorus (P2O5)</td>
<td>0.4 to 0.8</td>
<td>0.6</td>
<td>0.5 to 0.8</td>
</tr>
<tr>
<td>Potassium (K2O)</td>
<td>0.5 to 1.9</td>
<td>1.2</td>
<td>0.5 to 0.8</td>
</tr>
</tbody>
</table>

Furthermore, the complete digestion of cattle dung in a biogas plant destroys weed seeds and organisms that can cause plant diseases.

#### 8.4 Influence of slurry on crop yields

There is increasing attention being given by the promoters of the technology and scientists in generating sufficient scientific data regarding the influence of slurry on the growth and yield of crops and vegetables. The data to date indicates that the yield of crops and vegetables can consistently be increased from 10 to 30 percent through slurry application.
References


[4] Biogas China, Prof. Li Kangmin and Dr. Mae-Wan Ho, I-SIS, 2006

[5] Biogas Technology for poverty reduction and sustainable development, BP Nema, Central Institute of Agricultural Engineering (Indian Council of Agricultural Research) Bhopal 462038, India


[24] Integrated economics & ecological farming and waste recycling & management systems, Prof. George L. Chan, ZERI International

[25] Correspondence with Professor, George Chan, ZERI

[26] Integrated Farming/Food & Waste Eco-Management Systems, Prof. George L. Chan, Zeri International


[32] Integrated farming systems for efficient use of local resources, Lylian Rodríguez J, Thomas R Preston and Nguyen Van Lai


[34] How To Install A Polyethylene Biogas Plant; Francisco X. Aguilar


[36] Lotte C, Malene L and Hellek N 1995 Small scale biogas digesters in Turiani, Nronga and Amani Tanzania


[38] “Management and utilization of biodigesters in integrated farming systems, San Thy, University of Tropical Agriculture Foundation, Chamcar Daung, PO Box 2423, Phnom Penh 3, Cambodia, santhy@mekarn.org


[41] www.wikipedia.en.org
Annex A: Drawing of the 4 m³ digester
Annex B: Site evaluation guideline and checklist

<table>
<thead>
<tr>
<th>CLIENT NAME</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTACT PERSON</td>
<td></td>
</tr>
<tr>
<td>CONTACT TELEPHONE: LANDLINE</td>
<td></td>
</tr>
<tr>
<td>CONTACT TELEPHONE: CELL</td>
<td></td>
</tr>
<tr>
<td>CONTACT FAX</td>
<td></td>
</tr>
<tr>
<td>EMAIL</td>
<td></td>
</tr>
<tr>
<td>DIGESTER LOCATION</td>
<td></td>
</tr>
</tbody>
</table>

Minimum resources required:
- Pigs
- Cows
- etc

Describe the reasons mentioned by the client wanting to use biogas

If a farm, is the farmer the landlord? If not, what length of lease is left? (years)

Describe in general terms the site and layout where the digester is required. Drawing up of a plan of the property showing the existing structures and proposed system components i.e. digester, waste ducting inlet, outlet, reed bed & gas lines. Use a separate A4 page for the diagram.
<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the best location for the digester on a very steep slope? Are there</td>
</tr>
<tr>
<td>any other sites where the digester could be located where it is not so</td>
</tr>
<tr>
<td>steep? If not, what measures will be required to secure the digester if</td>
</tr>
<tr>
<td>built on the steep slope?</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Is this a new development, or will the digester be added to an existing</td>
</tr>
<tr>
<td>development?</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>What is the annual rainfall for this part of Fiji?</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Ask the client what the water table looks like (how deep). The digesters</td>
</tr>
<tr>
<td>should be located a minimum of 10m from a well or known ground water.</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>What is the soil like? Will excavation be easy – can it be done manually</td>
</tr>
<tr>
<td>? Will a machine be required?</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Does the site have good road access? Are there any aspects about the</td>
</tr>
<tr>
<td>access that the client can tell you?</td>
</tr>
</tbody>
</table>
If there are multiple sources of waste e.g. different houses, livestock pens, dairy, etc indicate how far apart they are. Also prepare a diagram or sketch of the site with distances between the sources indicated, as well as showing where the gas could be used e.g. kitchen. Photos are also useful.

<table>
<thead>
<tr>
<th>Source</th>
<th>Description of waste e.g. dairy, house</th>
<th>Distance to potential biogas site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Are there any other sources of other organic wastes?

<table>
<thead>
<tr>
<th>Waste</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen Scraps</td>
<td></td>
</tr>
<tr>
<td>Garden Scraps</td>
<td></td>
</tr>
<tr>
<td>Other?</td>
<td></td>
</tr>
</tbody>
</table>

What will the gas be used for and how much energy is needed?

<table>
<thead>
<tr>
<th>Energy form</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas for cooking</td>
<td></td>
</tr>
<tr>
<td>Gas for lighting</td>
<td></td>
</tr>
<tr>
<td>Gas for heating</td>
<td></td>
</tr>
<tr>
<td>Gas conversion to electricity</td>
<td></td>
</tr>
</tbody>
</table>

If there are livestock, indicate how many, of what type and how they are controlled

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
<th>Zero-grazed, penned at night, not penned at all:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goats</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pigs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Are the animals always on the farm? Do they ever get sold? Describe the cycle of
the animal population on the farm. Also describe whether the farmer intends to grow his livestock population in the future, and by what extent.

<table>
<thead>
<tr>
<th>House</th>
<th>Number of people</th>
<th>Occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Indicate for each house how many people there are and what the occupancy will be.

Indicate in quite specific terms how much water is currently been used, or what is expected in the future.

<table>
<thead>
<tr>
<th>Water Application</th>
<th>Amount (PER DAY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household</td>
<td></td>
</tr>
<tr>
<td>Garden</td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

The overflow from the digester is nutrient rich, and can either be further treated via a reed bed before being used on a garden, or not, depending on whether you have livestock or human wastes. If not, it would be cheaper to avoid using a reed bed and overflow in to a French drain.

Would you use this overflow on a garden?

If no, would you prefer the overflow to be diverted to a French Drain?

Indicate who would be available on site to:

| (a) Receive user training |
| (b) Be responsible for day-to-day feeding and maintenance of the digester. |

FOR OFFICE USE

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>Private waste management</th>
</tr>
</thead>
</table>

AGAMA Energy (Pty) Ltd

November 2006
<table>
<thead>
<tr>
<th>Private waste management + energy generation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial waste management</td>
<td></td>
</tr>
<tr>
<td>Commercial waste management + energy generation</td>
<td></td>
</tr>
</tbody>
</table>

Further investigation needed
### Annex C: Anaerobic Digester Comparison Chart

<table>
<thead>
<tr>
<th>Digester Model</th>
<th>Type</th>
<th>Typical Size (m³)</th>
<th>Average Install Cost/m³ (US$)***</th>
<th>Ideal total solid content of feedstock</th>
<th>Hydraulic Retention Time (days)</th>
<th>Temperature</th>
<th>Typical gas production per digester volume per day (m³/m³)</th>
<th>Estimated number of digesters worldwide</th>
<th>Installation skills and materials</th>
<th>Maintenance</th>
<th>Gas Storage</th>
<th>Settling tank required</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVIC</td>
<td>Floating Dome</td>
<td>4 - 10</td>
<td>$80.61</td>
<td>10%</td>
<td>20 - 55</td>
<td>ambient</td>
<td>0.2 - 0.6</td>
<td>&gt;2500</td>
<td>Brick laying</td>
<td>Check for free movement of dome</td>
<td>Constant pressure floating dome</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Chinese</td>
<td>Fixed Dome</td>
<td>6 - 15</td>
<td>$41.67</td>
<td>8%</td>
<td>40-60</td>
<td>ambient</td>
<td>No data</td>
<td>&gt;12,000,000</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure (0.12-1.5m) in fixed dome</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Janata</td>
<td>Fixed Dome</td>
<td>4 to 8</td>
<td>$63.33</td>
<td>8 - 10%</td>
<td>60</td>
<td>ambient</td>
<td>0.33</td>
<td>No data</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure in fixed dome</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Modified Janata Solid State</td>
<td>Fixed Dome</td>
<td>6</td>
<td>no data</td>
<td>14 - 16%</td>
<td>60</td>
<td>ambient</td>
<td>0.51</td>
<td>No data</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure in fixed dome</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Deenbandhu</td>
<td>Fixed Dome</td>
<td>6</td>
<td>$44.33</td>
<td>8 - 10%</td>
<td>55</td>
<td>ambient</td>
<td>0.70</td>
<td>&gt;1,000,000</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure (0.12-1.2m) in fixed dome</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Himshakti</td>
<td>Fixed Dome</td>
<td>1 - 2</td>
<td>$43.67</td>
<td>8 - 10%</td>
<td>60</td>
<td>ambient</td>
<td>0.77</td>
<td>&gt;100</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure in fixed dome</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>Size</td>
<td>Initial Cost</td>
<td>Sludge Removal</td>
<td>Biogas Production</td>
<td>Cracks Removal</td>
<td>Hydraulic Pressure</td>
<td>Installation Cost</td>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------</td>
<td>------</td>
<td>--------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>--------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAMARTEC</td>
<td>Fixed Dome</td>
<td>4 - 10</td>
<td>no data</td>
<td>8 - 10%</td>
<td>60</td>
<td>0.7***</td>
<td>&gt;150</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure (0.12-1.2m) in fixed dome</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nepalese</td>
<td>Fixed Dome</td>
<td>4 - 10</td>
<td>$57.50</td>
<td>8 - 10%</td>
<td>60</td>
<td>0.70***</td>
<td>&gt;150,000</td>
<td>High skill masonry</td>
<td>Every five years remove sludge and check for cracks</td>
<td>Hydraulic pressure (0.12-1.2m) in fixed dome</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGAMA</td>
<td>Fixed Dome</td>
<td>4 - 30</td>
<td>$315.00</td>
<td>8 - 10%</td>
<td>&gt;20</td>
<td>0.7</td>
<td>&gt;200</td>
<td>High skill masonry</td>
<td></td>
<td>Hydraulic pressure (0.6 - 1.0) in fixed dome</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UASB**</td>
<td>High Rate Anaerobic Reactor</td>
<td>5 to 75</td>
<td>$71 - $100</td>
<td>3 to 10%</td>
<td>1 day</td>
<td>tropical</td>
<td>No data</td>
<td>Masonary</td>
<td>Scum &amp; sludge removal every 3 days</td>
<td>flexible PVC digester</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGSB</td>
<td>High Rate Anaerobic Reactor</td>
<td>5 to 75</td>
<td>no data</td>
<td>1 to 8%</td>
<td>1 day</td>
<td>tropical or heated</td>
<td>No data</td>
<td>No data</td>
<td>Fibreplas or welding</td>
<td>Movement along PE bag</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaerobic Baffled</td>
<td>High Rate Anaerobic Reactor</td>
<td>10 to 30</td>
<td>no data</td>
<td>10%</td>
<td>1 day</td>
<td>tropical or heated</td>
<td>No data</td>
<td>No data</td>
<td>No data</td>
<td>Minimal to provide back pressure</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red Mud PVC Model</td>
<td>Plastic Bag</td>
<td>30 to 70</td>
<td>$30</td>
<td>10%</td>
<td>1 day</td>
<td>ambient</td>
<td>No data</td>
<td>&gt;50,000</td>
<td>low skill</td>
<td>Yes with hydraulic pressure</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Type</td>
<td>Mode of Operation</td>
<td>Polyethylene Tube</td>
<td>Plastic Tube</td>
<td>10 to 75</td>
<td>$5</td>
<td>5%</td>
<td>20 - 30 days</td>
<td>ambient</td>
<td>0.36</td>
<td>&gt;27000</td>
<td>low skill</td>
<td>Daily inoculation of influent with effluent</td>
<td>Yes with hydraulic pressure</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>--------------</td>
<td>----------</td>
<td>-----</td>
<td>----</td>
<td>--------------</td>
<td>---------</td>
<td>------</td>
<td>--------</td>
<td>-----------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Polyethylene Tube</td>
<td></td>
<td>$5</td>
<td>5%</td>
<td>20 - 30 days</td>
<td>ambient</td>
<td>0.36</td>
<td>&gt;27000</td>
<td>low skill</td>
<td>Daily inoculation of influent with effluent</td>
<td>Yes with hydraulic pressure</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug Flow Model</td>
<td>Plug Flow</td>
<td>10 to 75</td>
<td>unknown</td>
<td>3 to 12%</td>
<td>40 days</td>
<td>ambient</td>
<td>0.29 - 0.42</td>
<td>no data</td>
<td>Earthmoving</td>
<td>Remove sludge every 16 years (EPA Agstar)</td>
<td>Yes with hydraulic pressure</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Anaerobic Lagoon</td>
<td>Covered Lagoon</td>
<td>&gt;100</td>
<td>$5.65</td>
<td>3%</td>
<td>40 - 60 days</td>
<td>warm climates</td>
<td>no data</td>
<td>no data</td>
<td>Earthmoving</td>
<td>Remove sludge every 16 years (EPA Agstar)</td>
<td>Internal and external</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Batch Wet</td>
<td>Wet Fermentation</td>
<td>no data</td>
<td>$5 *</td>
<td>12.50%</td>
<td>30 days</td>
<td>30°C</td>
<td>1.0</td>
<td>no data</td>
<td>Low</td>
<td>Bag or tank emptied at the end of the process</td>
<td>External gas holder</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Batch Dry</td>
<td>Dry Fermentation</td>
<td>no data</td>
<td>$5 *</td>
<td>25%</td>
<td>60 days</td>
<td>35°C</td>
<td>0.79</td>
<td>no data</td>
<td>Low</td>
<td>Bag or tank emptied at the end of the process</td>
<td>External gas holder</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

* Assuming PE bag fabrication

** ZERI design digesters

*** Assumed efficiency is equivalent to the Deenbandhu digester

**** This value depends highly on the country of installation, and it's related to GDP, labour and material costs

AGAMA Energy (Pty) Ltd November 2006