IMPROVING RURAL LIVELIHOODS THROUGH BIOGAS GENERATION USING LIVESTOCK MANURE AND RAINWATER HARVESTING

VOLUME 2: GUIDELINES REPORT

MT Smith and TM Everson

WATER RESEARCH COMMISSION

TT 645/15

IMPROVING RURAL LIVELIHOODS THROUGH BIOGAS GENERATION USING LIVESTOCK MANURE AND RAINWATER HARVESTING

VOLUME 2: GUIDELINES REPORT

EDITORS: MT Smith and TM Everson

WATER RESEARCH COMMISSION

Report to the
WATER RESEARCH COMMISSION

by

University of KwaZulu-Natal
in association with
Rhodes University
and
University of Venda

WRC Report No. TT 645/15

January 2016

University of Venda

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Improving Rural Livelihoods through Biogas Generation using Livestock Manure and Rainwater Harvesting* (WRC project K5/1955)

This report forms part of a series of two reports. The other report is Rural Livelihoods through Biogas Generation using Livestock Manure and Rainwater Harvesting. Volume 1: Research Report (WRC Report No. 1955/1/15).

ISBN 978-1-4312-0733-6
Printed in the Republic of South Africa

contents

figures

tables

plates

acknowledgments

This project was in response to a directed call for projects initiated by the Water Research Commission (WRC) with published terms of reference. The WRC is gratefully acknowledged for providing funding, guidance, research management and administration. The universities of KwaZulu-Natal, Rhodes and Venda are thanked for facilitating the research and provision of research infrastructure. Special thanks are given to the participating households for their enthusiasm, monitoring and dedication during the project. We also wish to acknowledge contributions made by the active members of the reference group:

Dr S Mpandeli (Chairman)	*Water Research Commission (2012-2015)*
Dr A Sanewe (Chairman)	*Water Research Commission (2010-2011)*
Dr GR Backeberg	*Water Research Commission*
Dr JJ Botha	*ARC*
Prof M De Wit	*De Wit Sustainable Options*
Prof GPW Jewitt	*University of KwaZulu-Natal*
Dr IC Madakadze	*University of Pretoria*
Dr N Papenfus	*Dams for Africa*
Mr K Zihlangu	*Department of Energy*

RESEARCH TEAM

University of KwaZulu-Natal

- Dr Terry Everson
- Mr Mike Smith
- Prof Colin Everson
- Dr Monique Salomon

Rhodes University

- Prof James Gambiza

University of Venda

- Dr David Tinarwo
- Dr Joseph Baloyi

Agama Energy

- Mr Greg Austin

CHAPTER 1: GUIDELINES FOR GRAZING MANAGEMENT

Authors: Everson T and Baloyi J




1.1 INTRODUCTION

Increasing fodder production has become essential to solve the problem of diminishing natural grazing veld for livestock in rangeland systems. These guidelines were developed to assist livestock owners with biodigesters to implement sustainable grazing management practices. This was achieved through determining methods for improving grazing capacity and livestock production in three communal areas in the Eastern Cape, KwaZulu-Natal and Limpopo Provinces. Communal rangelands (Plate 1-1) are defined as "those areas where agriculture is largely subsistence-based and where rangelands are generally communally-owned and managed as opposed to private or individual ownership" (Everson & Hatch, 1999). In all three provinces continuous grazing is practised whereby animals graze in the same area for the entire grazing period (Tainton, 1999).

Plate 1-1: Communal rangelands in the Upper uThukela, KwaZulu-Natal.

Continuous grazing works best in homogeneous grasslands and has the advantage that animals have free access to all the available forage (Plate 1-2). In the past, herders were able to implement periods of rest to enable the rangeland to recover. Resting is probably the most critical element in any grazing management programme since damage to grasses can be mitigated with appropriate rest (Tainton, 1999).

Plate 1-2: Continuous grazing in a communal rangeland.

1.2 CHALLENGES FACING COMMUNAL LIVESTOCK OWNERS:

- Continuous grazing can result in selective grazing of areas and species which can lead to preferred areas being over-grazed (Plate 1-3).
- With the breakdown of the herding system, it is difficult to apply rests to communal rangeland.
- There is a decline of nutrients in sourveld during the winter season (Plate 1-4).
- Land use changes and degradation have led to fodder shortage which has significant effects on animal performance (Plate 1-5).
- Shortage of land has a negative impact on stocking rate.

Plate 1-3: Fodder shortage in communal areas.

Plate 1-4: Livestock utilize maize stover in winter when veld nutrients are depleted.

Plate 1-5: Degradation caused by cattle access routes to grazing areas.

1.3 WHAT IS STOCKING RATE?

Stocking rate is the number of animals per unit area for a given time. Stocking rate affects grassland condition by altering the herbage production and botanical composition (plant physiology and long-term species composition) (Edwards, 1980; Fynn and O'Connor, 2000). There are a number of options to manage stocking rate for sustainable land-use (Table 1-1).

Table 1-1: Options for managing stocking rate for sustainable land-use.

OPTION	ADVANTAGE	DISADVANTAGE
Supplementing rangeland forage with protein licks and concentrates	• Supplies limiting minerals, protein and energy to animal which improves digestibility of the veld grasses	• High cost therefore not economically feasible in communal areas
Provide planted pastures for alternative feed	• High yields of nutritious grasses	• High cost of implementation • High moisture requirements • Poor availability of seed
Implementation of agroforestry systems	• Increases fodder production through tree leaves and pods	• Availability of suitable non-invasive species • High cost of tree protection from livestock
Establishment of fodder banks close to the farmer's homestead	• Nutritious and palatable crops provide high quality supplements for livestock	• Selection of suitable species • Insect and pest damage • Some species require fertile soil

In this study we examined the option of the establishment of fodder banks close to the farmer's homestead. This was based on the proximity of the biodigesters and bioslurry at the homesteads. A number of different fodder crops were tested in the three provinces to provide farmers with a range of options.

1.3.1 Criteria for fodder crop selection

- The crops were selected based on climatic conditions for the three provinces
- Farmers' current practices were assessed to facilitate acceptability of crop
- The potential fodder crops had to have moderate input resources.

In KwaZulu-Natal the crops tested were Napier grass (*Pennisetum purpureum*), an annual legume *Vigna sinensis* (cow pea) and an annual grass *Sorghum bicolor* (sorghum). In Limpopo the tested crops were guinea grass (*Panicum maximum*) and Napier grass. In the Eastern Cape four crops were tested including an annual legume *Trifolium vesiculosum* (arrow leaf clover), an annual grass *Avena sativa* (oats), a perennial legume *Trifolium repens* (white clover) and a perennial grass *Festuca arundinaceae* (tall fescue).

1.3.1.1 Napier grass (*Pennisetum purpureum*)

General

- Successfully grown in Kenya for zero-grazing systems whereby cattle are confined in one place where feed and water are brought to the animals.
- Suitable for regions with annual rainfall ranging from 750 to 2500 mm.
- Napier grass is one of the top three grasses that can be grown successfully at different agro-ecological regions, making it a resilient crop.

Plate 1-6: Napier grass (*Pennisentum purpureum*).

- It is an ideal crop for smallholder farmers because it can grow as a main crop or intercrop.
- It propagates vegetatively.
- It has a deep root system which can draw moisture from the sub-soil, allowing it to withstand droughts.

Planting

- Napier fodder can be propagated through cuttings in a similar manner to sugar cane.
- The stem is cut into sections called setts (approximately 0.5 m) which each contain three nodes.
- The cuttings are hand pushed into furrows (inter-row spacing = 1.25 m; inter-plant spacing = 0.9 m) at a soil depth of 0.15-0.2 m.
- Two nodes are buried underground at an angle of 30-45˚, leaving one node above ground surface.
- During the first two weeks after planting, plants are hand watered daily to enhance establishment.
- Bi-weekly application of bioslurry should be applied once the plants are established.

Fertilization

- Pour two and a half litres of a bioslurry and water solution mixed at a 1:1 ratio (five litres in total) into a furrow around the plant. This prevents bioslurry wastage due to runoff.
- Use the soil on the edges of the furrow to cover the bioslurry so that it seeps into the soil.
- During the first two weeks of establishment apply 5 litres water to the plants daily by hand.
- Weed three weeks after planting and thereafter when necessary. As the Napier cover increases, weed survival decreases.

Harvesting

- The recommended height for harvesting is when the plant is 0.6-0.9 m high.
- The plant stem is cut at approximately 0.15 m above the ground so that at least one node remains undamaged above the ground. This facilitates regrowth.

1.3.1.2 Cow pea (Vigna unguiculata)

General

- Cow pea is a major source of protein (20-25%) and vitamins for both humans and animals.
- Too much rainfall can affect crop growth especially the leaves causing leaf diseases.
- Cow peas are sensitive to frost and cold but are tolerant of drought.
- Cow pea is a good nutritious fodder which can be used in many forms as a green manure and cover crop.

Plate 1-7: Cow pea (*Vigna unguiculata*).

- Cow pea is a legume which has the ability to fix nitrogen about 80 to 90% in the soils. It is a therefore a good intercrop in fodder production.
- Cow pea yields differ with the purpose of production. For seed the yield is estimated at 1-1.2, for hay 4-6 and silage 7-8 tons ha^{-1} (DAFF, 2011; Smith, 2006).

Planting

- Seeds were provided by the Southern African Cover Crop Solutions (SACCS).
- The cultivar used was mixed brown cow pea.
- In cool areas, the planting time for cow pea is in mid-November while in warm areas the planting is in mid-December.
- Plants are planted no deeper than 50 mm.
- Plant row depends on the growth type of cow pea plant (upright or semi-runner). For the upright type the spacing between rows is 900 mm and the inter-row spacing is 100 mm. For the semi runner types the spacing between rows is 1500 mm and the inter-row spacing is 100 mm (Smith, 2006).

Fertilization

- There is no need to add nitrogen (N) as cow pea is a legume which fixes nitrogen and can return 20-30 kg N ha^{-1} in the soil (Smith, 2006).
- Generally 20-30 kg phosphorus (P) ha-1 is applied depending on the soil P status.
- In this trial mono-ammonium phosphate (MAP) fertilizer was used following the recommendations of the Department of Agriculture (DOA) based on the results of soil analysis. MAP fertilizer was applied once during planting at 100 kg ha^{-1}.
- Bioslurry was diluted to a 1:1 ratio with water and was applied biweekly at a rate of 8 tons ha^{-1}.

1.3.1.3 Sorghum (*Sorghum bicolor*)

General

Plate 1-8: Sorghum (*Sorghum bicolor*).

- Sorghum is indigenous to Africa.
- It is a nutritious and palatable fodder crop for livestock (hay and fodder) and chickens (grain).
- It can be fed as green fodder in summer and as hay during winter
- Sorghum is tolerant to drought and heat.
- It is water efficient and can grow well under rain-fed condition where water is scarce. It is therefore suitable for farmers in communal areas.
- Sorghum fodder contains more than 50% digestible nutrients with about 8% protein, 2, 5% fat and 45% nitrogen free extract.

Planting

- Sorghum seeds were provided by SACCS.
- The cultivar used in this trial was forage sorghum.
- Sorghum can be planted from late October to mid-December.
- Planting date varies with cultivars; early maturing cultivars can be planted until Mid- December.
- Sorghum can be planted at a depth of 50-70 mm for light soils and 30-50 mm for heavier soils.
- Spacing is 900 mm x 50 mm for inter and intra row spacing.
- Estimated yield in dry land is 3-6.5 ton ha^{-1}, for irrigated 7-9.5 and silage 30-50 ton ha^{-1}.

Fertilization

- Fertilizer application depends on the soil fertility status and the targeted yield.
- In this trial mono-ammonium phosphate (MAP) fertilizer was used following the recommendations of the Department of Agriculture (DoA) based on the results of soil analysis. MAP fertilizer was applied once during planting at 100kg ha^{-1}.
- Bioslurry was diluted to a 1:1 ratio with water and was applied biweekly at a rate of 8 tons ha^{-1}.

1.4 CASE STUDY: FODDER PRODUCTION IN KWAZULU-NATAL

Any grazing management programme needs an estimate of the available fodder and the carrying capacity. This can be done by experts in this field or through community capacity building programmes (Plate 1-9). One of the study sites, Potshini, was selected for the case study for KwaZulu-Natal to demonstrate the impact of supplementation with Napier fodder (with and without bioslurry) on the carrying capacity of this ward.

Plate 1-9: Community members carrying out a veld condition assessment.

1.4.1 What is carrying capacity?

The carrying capacity for the grazing area represents the maximum number of animal units (AU) that can be sustained without causing a downward trend in rangeland health (Tainton, 1999).

1.4.2 How do you estimate carrying capacity?

The carrying capacity is normally based on the standard biomass (i.e. 450 kg) and forage requirements of one animal unit (AU). For this guidelines report this value was adjusted for communal livestock to 0.75 AU (i.e. 375 kg) as these have lower forage requirements when compared to commercial livestock (Meissner, 1982).

<u>The following values must be determined:</u>

- Estimate the area. The Potshini grazing area was 218 ha (Plate 1-10).
- Determine the veld condition – this is based on the species composition, basal cover, topography and soil erodibility.
- There are a number of standard techniques to determine veld condition. In this study the benchmark technique was used whereby species composition of the study area is compared to that of veld in excellent condition (the benchmark) (Tainton, 1999).
- Veld condition – Take 200 nearest plant species identification measurements using a Levy Bridge.

Plate 1-10: The Potshini grazing area.

- Basal cover – Place a metal pin/stake randomly 50 times in the rangeland and measure the distance to the nearest tuft and the diameter of that tuft. Calculate the basal cover (Hardy and Tainton 2007) of the sample site (BCS) using equation 1.

BCS = 19.8 + 0.39(D) – 11.87(loged) + 0.64(d) + 2.93 (loged) **Equation 1**

Where:

D = mean distance to the tuft (cm)
d = mean diameter of the tuft (cm)

Determine livestock numbers (Stocking density):

For this case study a participatory mapping exercise was carried out to determine the number of households, livestock and boundaries of each sub ward in Potshini. Community members mapped the area indicating its boundaries and key resources (e.g. schools, streams, rivers, mountain, grazing land, crop field, homesteads) (Plate 1-11). Each individual marked the location of their homestead and then selected bean seeds indicating the number of cattle at their homestead. The stocking density recorded for 34 livestock owners was 378 AU.

Plate 1-11: Participatory rural appraisal mapping exercise of key resources in Potshini.

- Available forage resources – These are calculated from the forage requirements for each animal unit (Camp and Smith, 1997), the fodder supply of the natural veld (Everson et al., 2012), and compared to the fodder production of Napier grass with and without bioslurry (Table 1-2).

Table 1-2: Total biomass production (tons ha^{-1}) in the control and bioslurry treatments at the different experimental sites.

EXPERIMENTAL SITE	BIOMASS	
	CONTROL	BIOSLURRY
1	4,70	3,10
2	18,7	26,3
3	33,9	48,2
Mean	11,9	25,9

- The veld condition of the sites was poor ranging from 34.5% to 48.9% (Table 1-3). The veld condition scores were used in the following equations to determine the current grazing capacity (Tainton, 1999):

Table 1-3: Summary of veld condition and carrying capacity.

VARIABLES	SITE 1	SITE 2	SITE 3	MEAN	TOTAL
Veld Condition	34.50	41.30	48.90	41.60	-
Area (ha)	82.00	88.00	48.00	72.66	218
Current Grazing Capacity (AU ha^{-1})	00.19	00.23	00.28	00.32	-
Basal cover (%)	-	-	-	16.00	-
Total AU	-	-	-	-	378

CGC = PGC * numerical rating for the site **Equation 2**

Where PGC = potential grazing capacity i.e. grazing capacity of benchmark = 0.7 AU ha^{-1}

Numerical rating = CF + BCF + TF + SEF **Equation 3**

Where **CF** (composition factor) = 0.25 [(veld condition score + number of units of Increaser (I) species in excess of the benchmark)/100] = 0.104

BCF (basal cover factor) = -0.75 + 2 (BCS/BCB) – (BCS/BCB) ^{2} **Equation 4**

Where:

1: BCS = basal cover of the sample site (16.7%)

2: BCB = basal cover of the benchmark (12 %)

3: BCF = 0.097

TF (topographic factor) = 0.0 (slope > 15%, severely eroded)

SEF (soil erodibility factor) = 0.13 (shallow, moderate to high erodibility).

Numerical rating = CF + BCF + TF + SEF= 0.104 + 0.097 + 0.0 + 0.13 = 0.33

Current grazing capacity (CGC) = PGC * numerical rating for the site

= 0. 7 AU ha^{-1} *0.33

= 0.23 AU ha^{-1}

Using Potshini as an example which has a land area = 218 ha

Potshini can support 50 AU according to the veld condition (218 ha * 0.23 AU ha^{-1})
If we use 0.75 Animal Unit Equivalent (recommendation for communal areas since an animal unit is 375 kg as opposed to a commercial cow of 450 kg, the area can support 68 AU (50/0.75)

Forage requirements:

- Herbage consumption (tons AU^{-1} yr^{-1}) = 2.5
- If we assume communal cow consumes 0.75 of a commercial cow = 1.88 tons

Therefore, 378 AU will consume **710 tons** (1.88 tons X 378 AU) in 218 ha yr^{-1}

Forage supply:

- The natural veld Bioresource Group 8 (Moist Highland Sourveld) at a veld condition of 40% produces 1.195 tons ha^{-1}

Therefore, total land area produces **260 tons** (1.195 tons ha^{-1}* 218 ha)

Forage shortfall:

- 710 – 260 = **450 tons**

This indicates that the veld is overstocked at 2.7 times more than its grazing capacity. However, with supplementary feeding of Napier fodder it might be sustainable:

Napier Fodder production:
Area required to produce the sufficient fodder for a year of animals stocked at current stocking density

Control Napier biomass	= 11.9 tons ha^{-1}
	= 450 tons/ 11.9 tons ha^{-1}
	= 38 ha
Bioslurry Napier biomass	= 25.9 tons ha^{-1}
	= 450 tons/ 25.9 tons ha^{-1}
	= 17 ha

The trials therefore indicate that approximately 17 ha planted with Napier grass which is fertilized with bioslurry will be enough fodder to maintain the current stocking rate.

1.4.3 Outcomes of experimental Napier fodder trials in KwaZulu-Natal

- In Potshini the communal rangeland is stocked at approximately 2.7 times the carrying capacity and therefore it is degrading rapidly.
- Napier fodder biomass production is highly variable. In KZN biomass in the three study sites ranged from 3.10 to 33.9 tons ha^{-1} (Table 1-3).
- In the first year of bioslurry application there was no significant difference in the biomass of the bioslurry and control plots.
- The high mean biomass of the bioslurry (25.9 tons ha^{-1}) and the control plots (11.9 tons ha^{-1}), when compared to the biomass of the natural veld (1.195 tons ha^{-1}) has significant benefits for communal livestock owners.
- One option is the implementation of a semi-zero grazing system where animals are stalled for certain periods where they are fed Napier fodder, and are free-grazed for others where they feed on the rangeland.
- The kraaling of animals in a semi-zero grazing system promotes the easy collection of manure for the biodigester, a reduction in the occurrence of stock theft and a decrease in time spent on herding the animals.
- The results of this study support the implementation of a semi zero grazing system whereby <17 ha planted with Napier grass which is fertilized with bioslurry will be enough fodder for 34 livestock owners to maintain their current stocking density of 378 AU.
- This study has shown that with the use of bioslurry as a fertilizer, land area in the communal rangelands of the KZN can be optimized to produce higher biomass to feed more cows on marginal land.

1.5 CASE STUDY: FODDER PRODUCTION IN LIMPOPO PROVINCE

Napier and *Panicum* grasses were grown at Nthabalala (23.26 °S and 29.97 °E) and Maila (22.933 °S and 30.467 °E) in Elim, 35 km south of Louis Trichardt in the Makhado Municipality of Limpopo province. Daily average temperatures in summer at both sites range between 20 and 22.5°C in summer. Average winter temperatures are between 10°C and 15°C. Maximum daily temperatures can reach as high as 35°C. Annual average rainfall at Nthabalala and Maila is 401 and 600 mm respectively.

1.5.1 Land preparation for planting Napier and Panicum grasses

- Land preparation (Plate 1-12 a and b) can be done by either ploughing or digging early before the rainy season to enable other activities like planting to take place at the right time.
- Where terrain is steep, terracing should be done after clearing the land and then the seed bed should be demarcated (Plate 1-12 a).
- Uniformly irrigate the plots to ensure soil moisture for germination and sprouting (Plate 1-12 c).

(a)

(b)

(c)

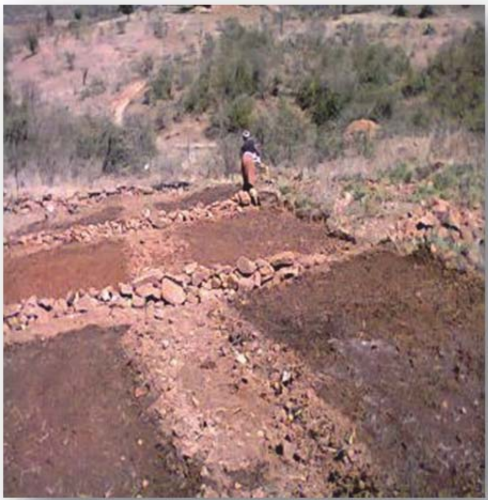


Plate 1-12: Prepared and terraced land with demarcated plots (from left, (a), (b), (c)).

1.5.1.1 Napier grass production

Planting

- Vegetative Napier cuttings with three nodes (Plate 1-13) are planted, with two nodes in the ground and one above ground level at an angle of about 30-45˚. Spacing is 75 cm between the inter-row and 75 cm intra-row (Plate 1-13 b and c) and detailed in Figure 1-1 below.

- Uniform irrigation (Plate 1-13 b) is also preferable until the grass start sprouting then the slurry irrigation treatment can be then applied.

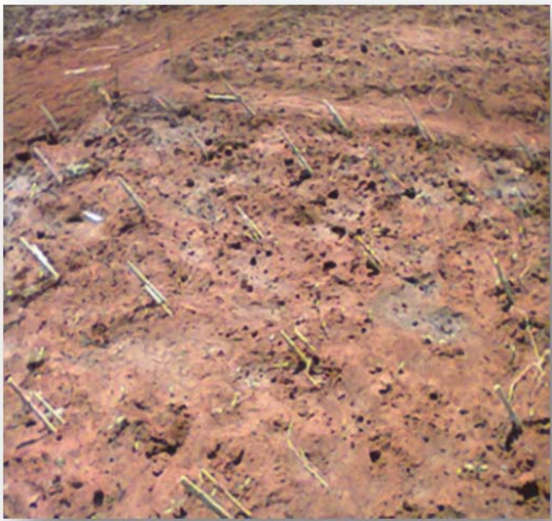


Plate 1-13: The vegetative Napier cuttings (left) and the planted roots (right).

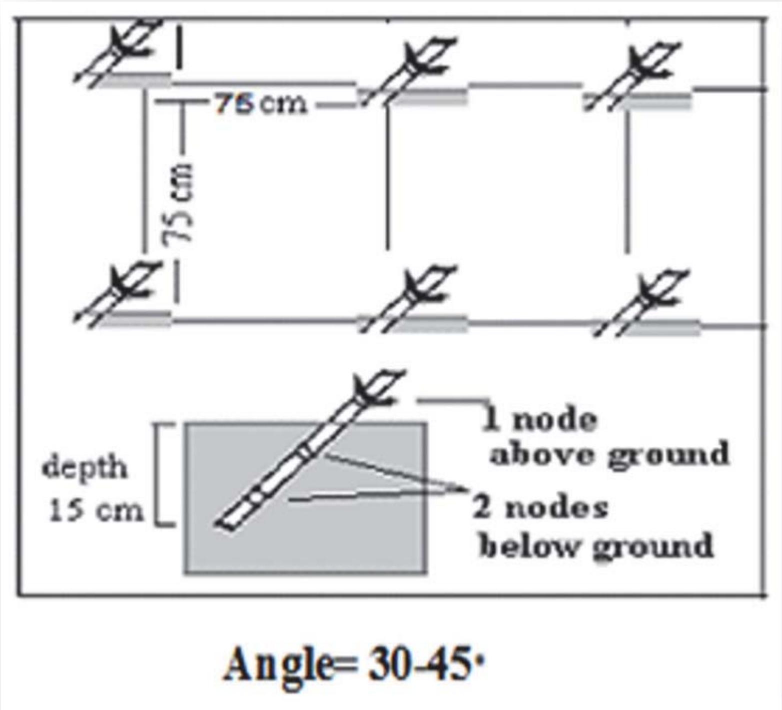


Figure 1-1: Planting layout of Napier cuttings.

Napier grass sprouting

- The sprouts from the node above the ground are observed earlier before the shoots from buried nodes in the ground (Plate 1-14).
- Sprouting occurs on the second or third week after planting depending on the hardness of the cutting and its node, mostly less harder cuttings with some nodes showing they sprout earlier.
- After about three weeks dry cuttings can be replaced with fresh cuttings.
- Irrigation can be done by watering can using 10 litres water per row. A day after irrigation the soil should be incorporated with bioslurry.
- Weeding should take place as early as possible after planting to eliminate undesirable plants. The area should be kept weed free throughout growth.

Plate 1-14: Sprouting Napier grass.

Early growth stage

- Once the Napier plants have established well, they should start to tiller and produce tall and high yielding forage plants (Plate 1-15).
- Weeding of unwanted plants to be done at this stage (Plate 1-16).

Plate 1-15: Napier grass at early stages, tillering and increasing the canopy.

Plate 1-16: Unwanted plants are 'weeded' out using a hoe.

Napier grass at the intermediate growth stage

- Napier grass at this stage (Plate 1-17) tends to cover most space and the canopy discourages weeds to grow.
- This is the stage where the grass grows faster by increasing the number of tillers and biomass.
- Watering can become more challenging as it is difficult to move between the rows.

Plate 1-17: Napier at intermediate stage.

Napier grass harvesting stage

- The first harvest of Napier grass, either to feed animals in a cut and carry system or to make silage, should be done when it reaches a height of 1-1.5 meters, which is usually three to four months after planting.
- The average yield of about 16 tons ha^{-1} can be achieved.
- At this stage Napier grass has high quality and sufficient dry matter. Thereafter the grass should be harvested at intervals of six to eight weeks, when it attains the same height of about 1.5 m.
- Harvesting at longer intervals produces higher dry matter yields, but crude fibre content increases and crude protein decreases resulting in lower digestibility, leaf-to stem ratios and ash contents.

Plate 1-18: Mature Napier at harvesting stage.

Napier grass regrowth stage

- After harvest approximately 10-15 cm of plant base is left to provide sufficient carbohydrate reserves for subsequent growth (Plate 1-20). This is especially important after the last harvest before the long dry period to promote fast growth after the onset of rains.
- It is suggested that hand weeding takes place after every harvest. Remove the dry root bound Napier grass to promote fodder regrowth by increasing soil aeration, and providing soil cover with mulching to improve water infiltration and decrease evaporation of soil water and loss of nutrients.

Plate 1-19: A team member inspecting the cut and sprouting Napier.

Plate 1-20: Napier regrowth at intermediate growth stage.

Chemical composition of Napier grass

- The chemical composition (e.g. crude protein, fibre, organic matter) of the Napier grown with or without poultry bioslurry at both Maila and Nthabalala showed no significant differences at the different stages of maturity.
- With the exception of magnesium which was higher in the bioslurry treatment at Maila, there were no significant differences in the nutrient composition (P, K, Ca. B, Fe, Mn and Mo) of Napier.
- Potassium was the most abundant mineral in poultry slurry compared to other nutrients. The order of nutrient content level in both poultry and cattle bioslurry was N >K >Mg >P >Ca. The order of nutrient content was similar for the two sites.
- High amount of nitrogen was in slurry at both sites compared to the South African fertilizer guide.

1.5.1.2 Panicum grass germination

- The Panicum grass seeds should be planted to a depth of 1 cm in rows spaced at 75 cm (Plate 1-21) and then thinned to 75 cm between plants in the same row (Plate 1-21).
- Seeding rate is 3 kg ha^{-1}.
- Irrigation can be done by watering can using 10 litres water per row. A day after irrigation the soil should be incorporated with bioslurry.

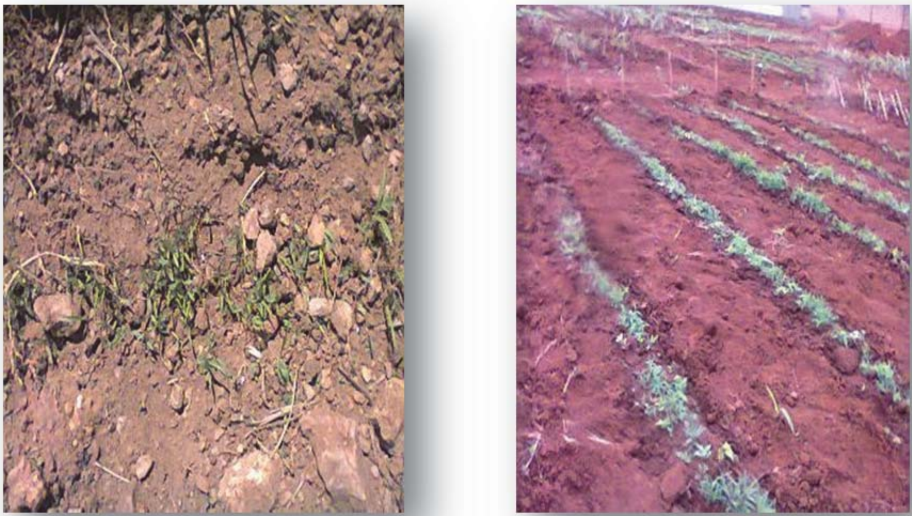


Plate 1-21: Panicum seeds germinating (left), and established seedlings (right).

- Panicum can be watered with a watering-can on a weekly basis from the early growth stage (Plate 1-22).
- The chosen rate of irrigation should be maintained for all the growth stages.

Plate 1-22: Panicum grass at early growth stage.

- At the intermediate stage and mature stage (Plate 1-22) the Panicum grass does not require much water for irrigation during rainy season.

Plate 1-23: Panicum grass at mature stage.

- Within two days of harvesting plants should be irrigated. Re-sprouting will occur two weeks after cutting Panicum.
- The regrowth of Panicum after cutting at the intermediate stage can produce more leaves and tillers (Plate 1-24).

Plate 1-24: Panicum grass after cutting at intermediate regrowth stage.

1.5.1.3 Napier grass conservation by making silage

- Lack of adequate and high quality feed, particularly in dry periods, is a major constraint to livestock production on smallholder farms.
- In some areas around Limpopo dry periods last long and during that period cattle could be sustained on conserved Napier grass from the high yields produced during the rainy season, when there is often an excess.
- Attempts have been made to make hay out of Napier grass but the succulent stems limit the rate of drying and with excess drying the stems may become hard and brittle and less palatable to livestock.
- The alternative is ensiling the surplus Napier since leaving Napier grass to become too mature may compromise the quality.
- Napier grass can be ensiled but the quality of silage obtained depends on fresh grass quality.
- The ensiling process and use of additives maximizes nutrient preservation. This is achieved by harvesting the crop at the proper age, minimizing the activities of plant enzymes and undesirable epiphytic micro-organisms (naturally present in the forage crop) and encouraging the dominance of lactic acid bacteria.

Silage making

- Harvest mature Napier grass (1.2 to 1.5 m) manually at about 15 cm above the ground using pruning shears.
- The harvested grass is immediately chopped to about 1.27 cm lengths (Aganga et al., 2005) using pruning shears.

- The chopped Napier grass is then compressed using hands to squeeze out air to promote an anaerobic condition.
- Carbohydrate additives namely: molasses, brown sugar and maize meal additive are mostly preferable for silage making.
- The additives can be added at 10% or 5% of the total weight of the chopped material (Moran, 2005). In order to be able to evenly spread the molasses on the chopped material, the molasses can be exposed to the sun in a container which makes it less thick and easier to spread.
- The additives add more value to the silage for future use for animal feeding (Plate 1-25).

Plate 1-25: Silage making in small 1.0 litre bottles.

The pH of an ensiled sample is a measure of its quality. The pH at the end of 42 days of ensiling Napier grown at Nthabalala is summarised in Table 1-4. All the additives increased the quality of the silage when compared to the control.

Table 1-4: pH of Napier grass silage with different additives (carbohydrates sources).

	Additive			
Treatment	**A**	**B**	**C**	**D**
Slurry	6.2 ±1.2[a]	3.5 ±0.2[c]	4.3 ±0.6[b]	3.9 ±0.3[b]
No slurry	6.2 ±0.7[a]	4.4 ±0.6[b]	3.8 ±0.3[b]	4.5 ±0.2[b]

[abc] *Means on the same row with different superscripts differ significantly (P < 0.05)*

A = Napier grass + no additive, B = Napier grass + brown sugar, C= Napier grass + molasses and D = Napier grass + maize meal

1.5.1.4 Conclusion

- Irrigating Panicum and Napier fodder with bioslurry from either poultry or cattle manure or using water only did not significantly affect growth parameters and yield of the two fodder grasses at both sites.
- The stage of maturity at harvesting significantly affected the quality of the forage.
- Addition of feed additives to the silage decreased the pH after 42-day ensiling thereby increasing silage quality.

1.6 GUIDELINES FOR INCREASING GRAZING CAPACITY FOR SMALLHOLDER FARMERS

Based on the results of this study, the following guidelines are recommended:

- Farmers should be encouraged to grow fodder crops to supplement livestock feeds from rangeland, promote controlled grazing, and encourage better management of both the range and livestock to ensure increased productivity and sustainability.
- On-farm demonstration plots should be established in each province to demonstrate and test forage species.
- In all provinces Napier fodder was the most promising fodder species because of its high production and quality.
- Seeds of forage crops should be available to farmers through the government extension service.
- The fodder crop should not compete with or displace food/cash crop.
- The fodder crop must be high yielding and nutritious.
- The fodder crop should be responsive to intensive management such as bioslurry application.
- It must be tolerant to frequent clipping.
- Fodder production should be increased by extending cultivation to currently fallow and unutilized lands.
- Farmers need to ensure that bioslurry is applied during favourable conditions such as when the soil is dry to avoid water logging.
- Bioslurry must be incorporated into the soil by breaking the soil crust which reduces infiltration rate.
- In some areas around Limpopo dry periods last long and during that period cattle could be sustained on conserved Napier grass from the high yields produced during the rainy season, when there is often an excess.
- The quality of excess fodder can be improved through ensiling. This ensures that livestock have high quality fodder during the winter or dry season.

CHAPTER 2: GUIDELINES FOR RAINWATER HARVESTING

Author: Everson CS

2.1 INTRODUCTION

One of the most critical factors in the operation of a biogas digester for biogas and bioslurry fertilizer is water. The digester has to be fed 20 litres a day to maintain biogas production. The total annual water use to run a biogas digester based on a daily usage of 20 litres per day is 7200 litre per year or 600 litres per month. However, access to water is a limiting factor for the households in this study. In the initial questionnaire survey carried out at the start of the study, 22% of households collect water from a river or stream, while 34% of households depend on a community tap for their primary source of water (Figure 2-1). Only 1% of households use water from a rainwater tank on their homestead as a tertiary source. Therefore the collection of 600 litres of water per month will place a heavy burden on households operating biodigesters.

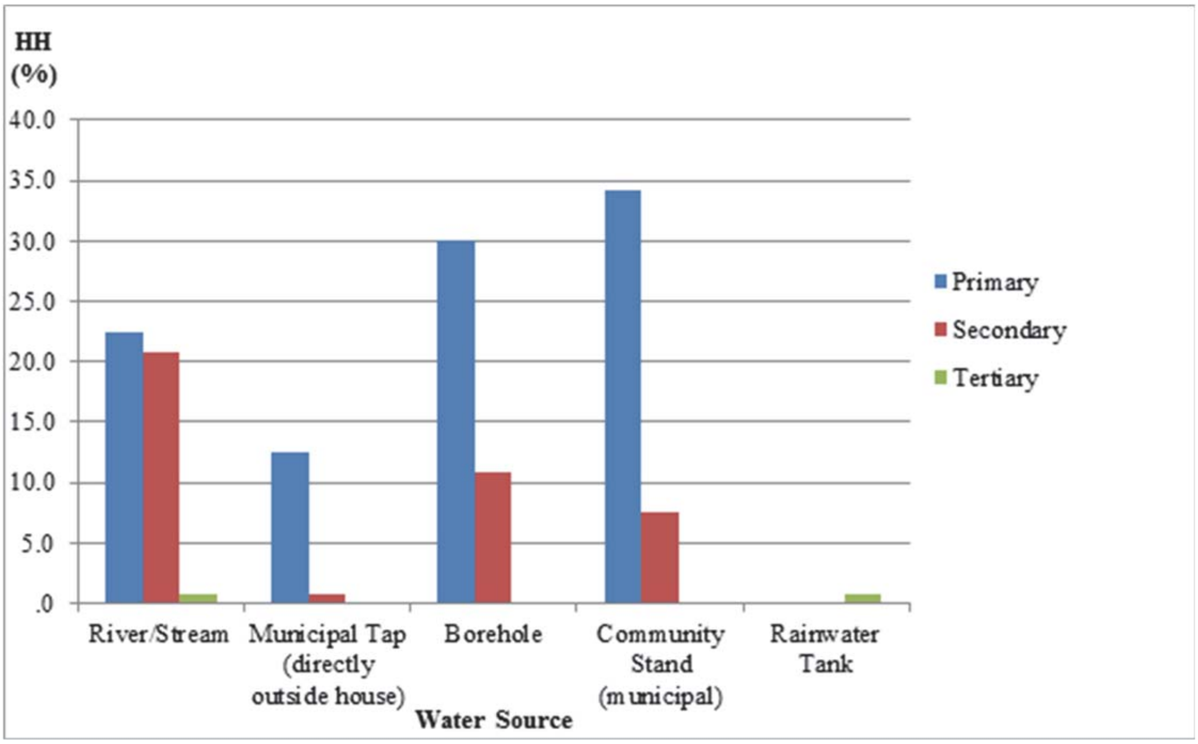


Figure 2-1: Water sources used by households at Okhombe in KZN.

2.2 CHOOSING A RAINWATER HARVESTING TECHNIQUE

In order to address the water requirements of households it is necessary to identify the most appropriate rainwater harvesting (RWH) techniques. The simple and practical categorisation recommended by Denison and Wotshela (2009) was followed and adjusted from the FAO (2003) categorisation (Figure 2-2). The classification is based on a scale and storage descriptor and adjusted for South African conditions (i.e. annual rainfall > 300 mm). The relationship between the type of water harvesting, rainfall and scale (size) is shown in Table 2-1. For this study micro-catchment rainwater harvesting was selected. This was further classified as non-field micro-catchment rainwater harvesting (Botha et al. 2014) since the water is required for domestic purposes to feed the biogas digester.

The 13 rainwater harvesting techniques recognised for use in South Africa (Denison et al., 2011) were analysed for feasibility and relevance for biogas production. From the analysis (Table 2-2) three possible appropriate techniques were identified that were relevant for biogas production. These were rooftop, greywater and mulching. However, in the study areas there were no easily available mulching materials which limited the application of this technique. The research component of this project focused mainly on the scale of rooftop water harvesting (Table 2-2). For domestic rainwater harvesting, rainwater is collected from rooftops, courtyards, compacted or treated surfaces and it is stored in RWH tanks and used for domestic purposes as outlined by Mwenge-Kahinda et al. (2008) in WRC project K5/1563. Storage tanks can be located underground or above ground.

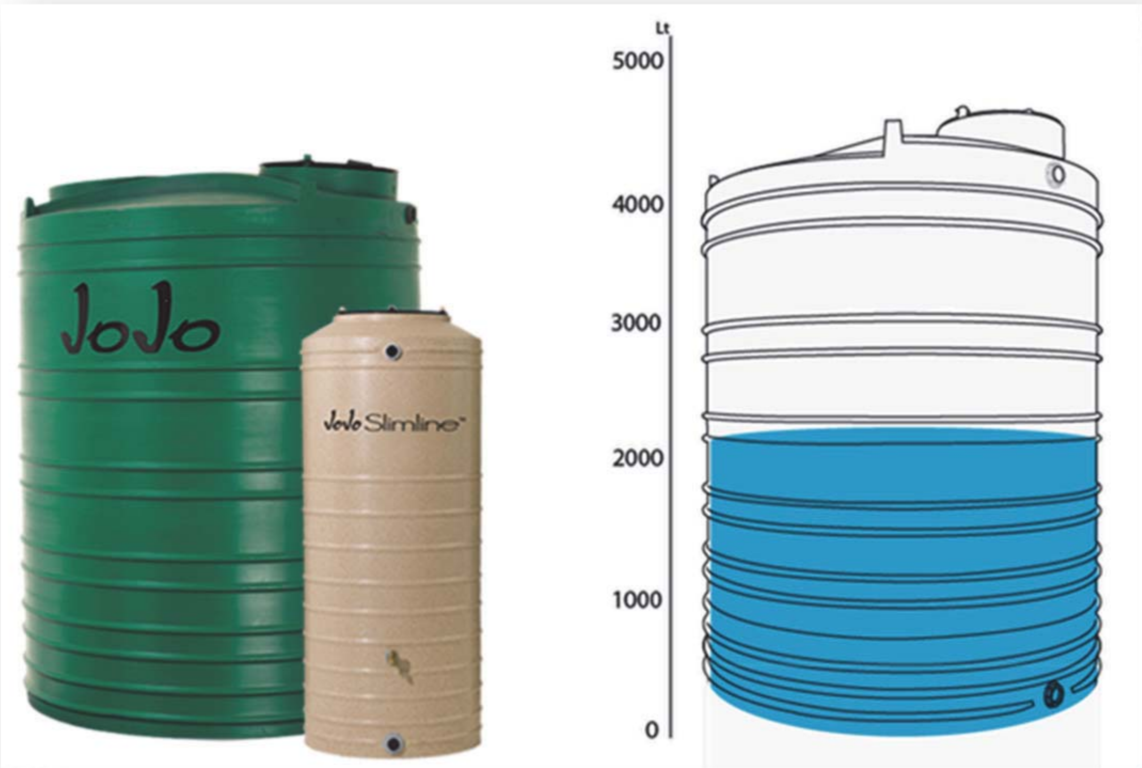


Plate 2-1: Water tank (source: JoJo Tanks, 2015).

2.3 SURVEYING AND PLANNING

Since the size of storage tank will depend on the rainfall of the study area and rooftop area, the first step in the implementation of RWH tanks is to survey each site and draw a detailed plan of the homestead. The following information must be surveyed on to the plan:

- Position and area of buildings with potential for rooftop RWH
- Size of fields for fodder production
- Distance of fields from the homestead
- Potential position of the biogas digester

- Position of the kraal and distance to the biogas digester
- Area and position of homestead gardens.

An example of a survey map with the above details is presented in Figure 2-3.

Table 2-1: Ratio of catchment, field size and flow type for water harvesting (WH) and conservation systems (taken from Denison and Wotsheba, 2009).

Type of WH	Kind of flow	Annual rainfall	Treatment of catchment	Size	Ratio
Micro-catchment	sheet and rill flow	> 200 - < 300 mm	treated or untreated	- 1000 m	1:1-10:1
Macro-catchment	turbulent runoff + channel flow	> 300 mm	treated or untreated	1000 m - 200 ha	10:1-100:1
Floodwater harvesting	flood water	> 150 mm	untreated	200 ha - 50 km^2	100:1-10,000:1

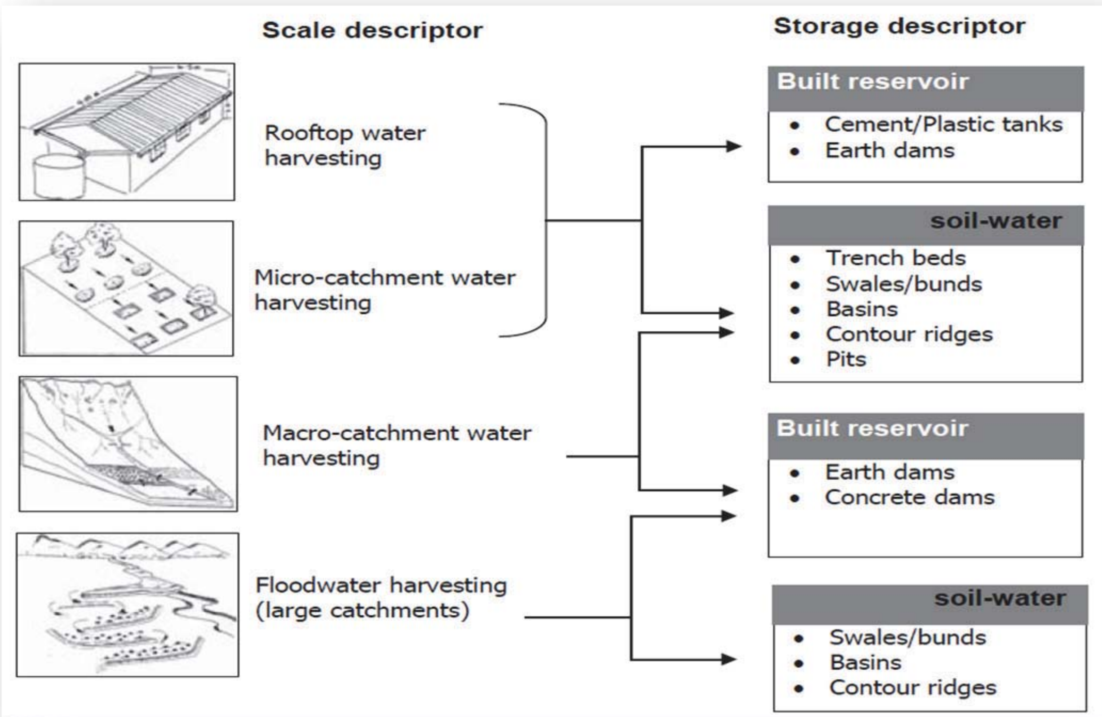


Figure 2-2: Categorisation of rainwater techniques (after Denison and Wotshela, 2009).

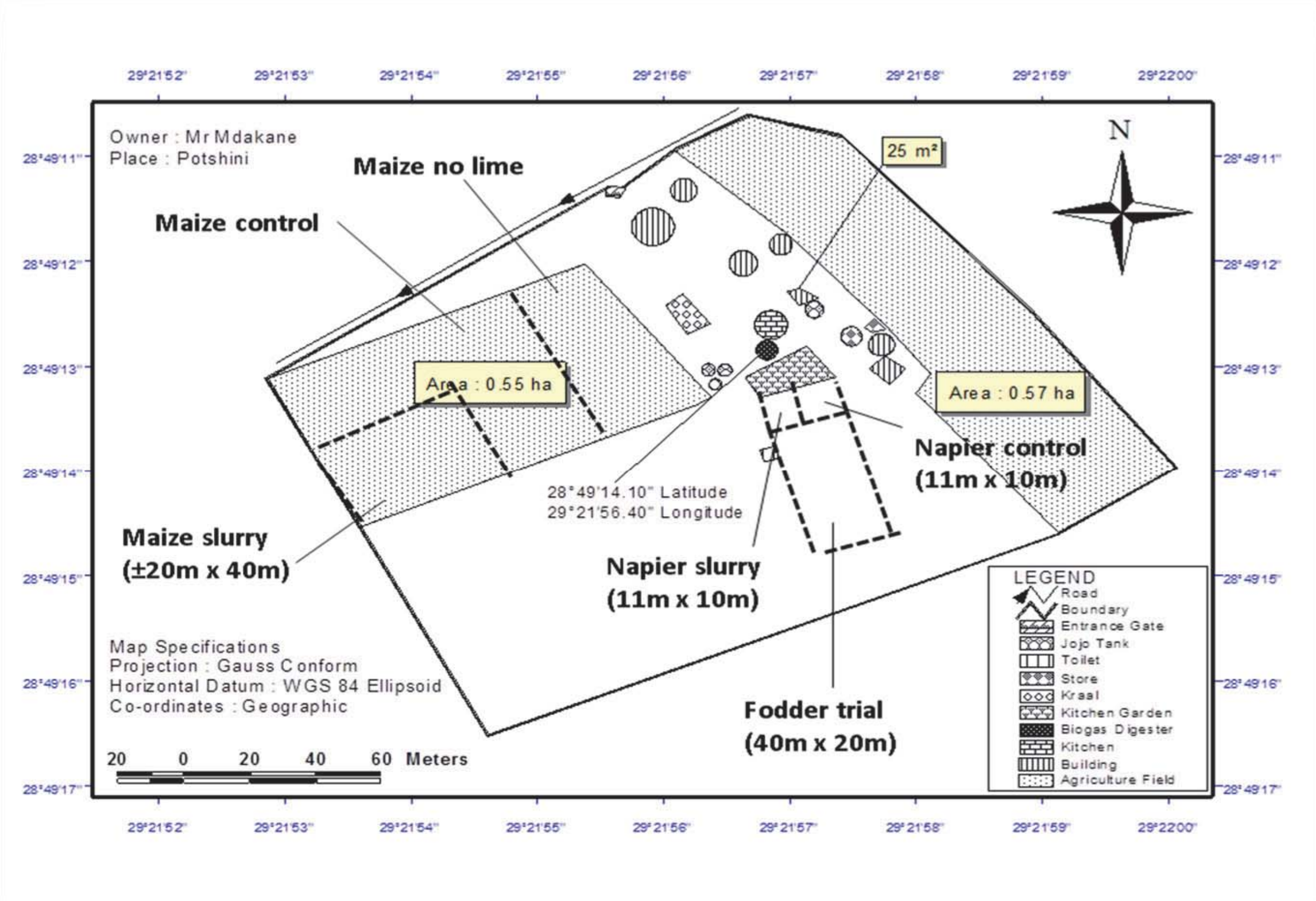


Figure 2-3: Surveyed plan map of a WRC K5/1955 pilot household.

Table 2-2: Selection of suitable water harvesting techniques for biogas production.

TECHNIQUE	FEASIBLE?	REASON	RELEVANCE TO BIOGAS PRODUCTION	TESTED
Roofwater harvesting	Yes	Available roof tops	High	Yes
Greywater harvesting	Yes	From domestic activities	High	Yes
Mulching	Yes but with difficulty	No material available	medium	No
Diversion furrows	Yes	Impervious runoff areas generally available at all sites	Medium	No
Trench beds	Yes	Small gardens	medium	No
Fertility pit	Yes	Any site	medium	No
Swales	No	Not suitable at homestead level		
Stone bunds	No	Not suitable at homestead level		
Tied ridges	No	Not suitable at homestead level		
Terraces	No	Not steep enough		
Ploegvore	No	Not suitable at homestead level		
Domewater	No	No suitable geological features		
Saaidamme	No	No floodplain or nearby ephemeral rivers		

2.4 DESIGN RAINFALL METHODOLOGY

Design rainfall analysis is a useful tool for determining the areas of roof tops that will be necessary to supply sufficient water to fill the capacity of the rainwater storage tanks that will be used to fill the biogas digesters. For the analysis it is essential to understand the climatic characteristics of the study site. The planning of water harvesting techniques for the study site needs to account for the appropriate "design" rainfall, which is the ratio of “run on” to planted or “run off” area (Critchely and Siegert, 1991).

To determine the probability exceedance of the annual rainfall totals for a study site, a graphical procedure of ranking the annual rainfall totals against their probability of occurrence and plotting on normal probability axes is applied to the long-term rainfall data. Long-term data series are required to make the data representative of the long-term rainfall patterns of the selected study site (Critchely and Siegert, 1991). For example, the long-term annual average rainfall in the Upper Thukela is 711 mm (Figure 2-4) and the distribution is distinctly seasonal, being wet between January and December (± 100 mm $month^{-1}$) and dry in winter (<20 mm $month^{-1}$). Since evaporation is a key factor affecting available water long-term evaporation data is essential for RWH planning. For example, the annual total Penman Monteith Reference evaporation for the Upper Thukela was 1219 mm and therefore 500 mm higher than the annual rainfall. Average daily PM varied between 6 and 4 mm day^{-1} in summer and winter respectively (Figure 2-5).

If we want to determine the roof top area and RWH tank size for the Upper Thukela, from the annual design rainfall statistics we can predict that the site will have a two out of three year probability (66%) of receiving 580 mm of annual rainfall and only a 33% probability of receiving the long-term average of 700 mm) (Figure 2-6). Considering the driest month (July) it was apparent that there is no confidence in receiving rainfall in the winter months at the 66% probability level and only a 33% chance of receiving 10 mm (Figure 2-7). The monthly rainfall is particularly low in June and July. It is therefore important to allow for at least 3 months of storage following the average long-term May rainfall of 24 mm (2400 ℓ on a 100 m^2 roof area). For these purposes a storage tank of 2500 ℓ would be adequate to store the water for biogas generation based on an input of water to the digester of 20 ℓ day^{-1}. The input from “grey” water from normal household activities such as washing and showering needs to be quantified and accounted for as it provides an additional source of water.

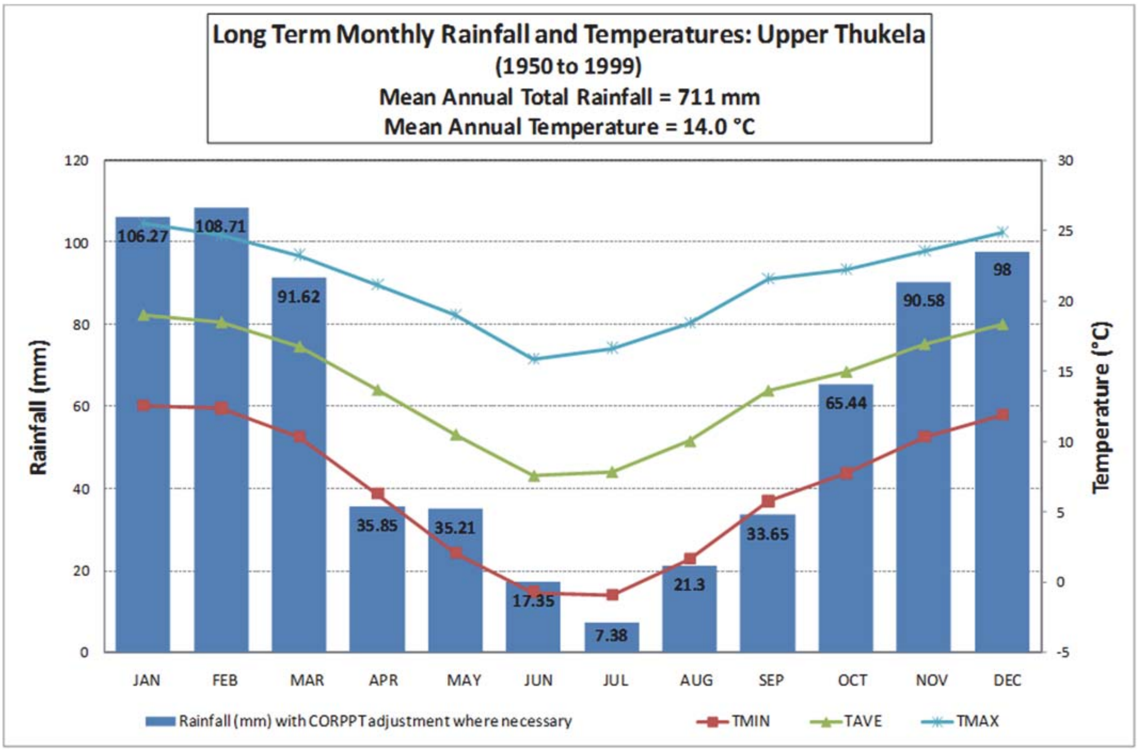


Figure 2-4: Long-term monthly rainfall and temperatures at Upper uThukela (KwaZulu-Natal).

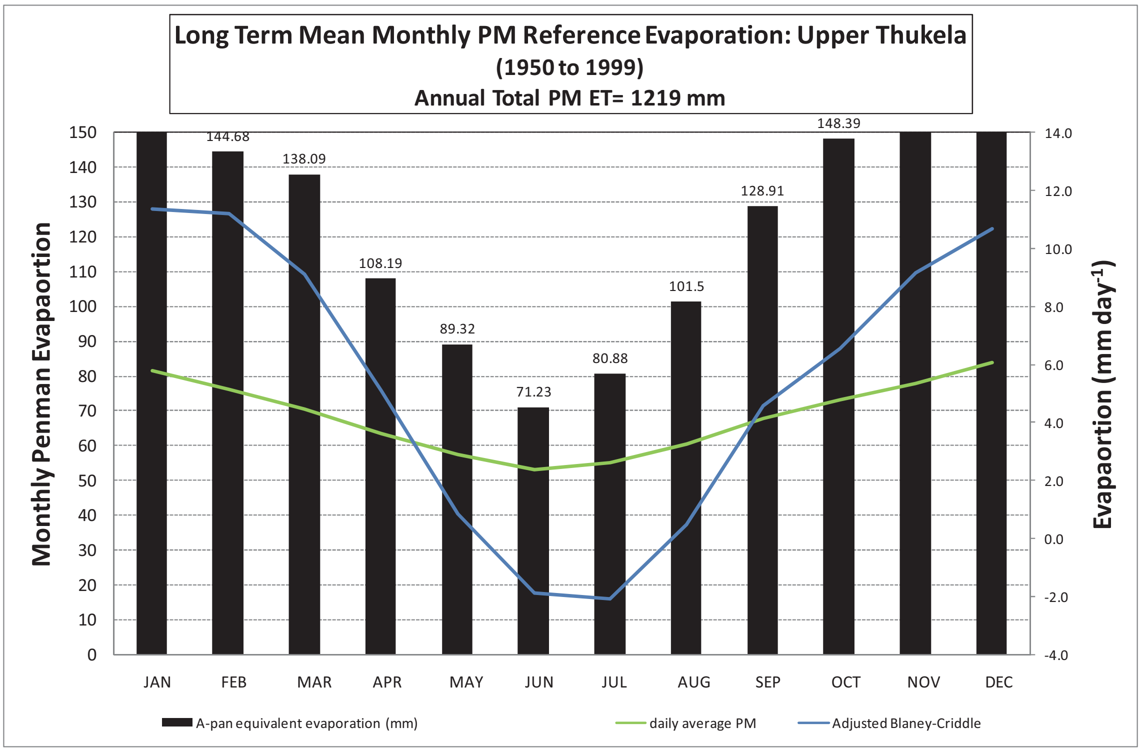


Figure 2-5: Long-term mean monthly and daily Penman-Monteith evaporation Upper uThukela.

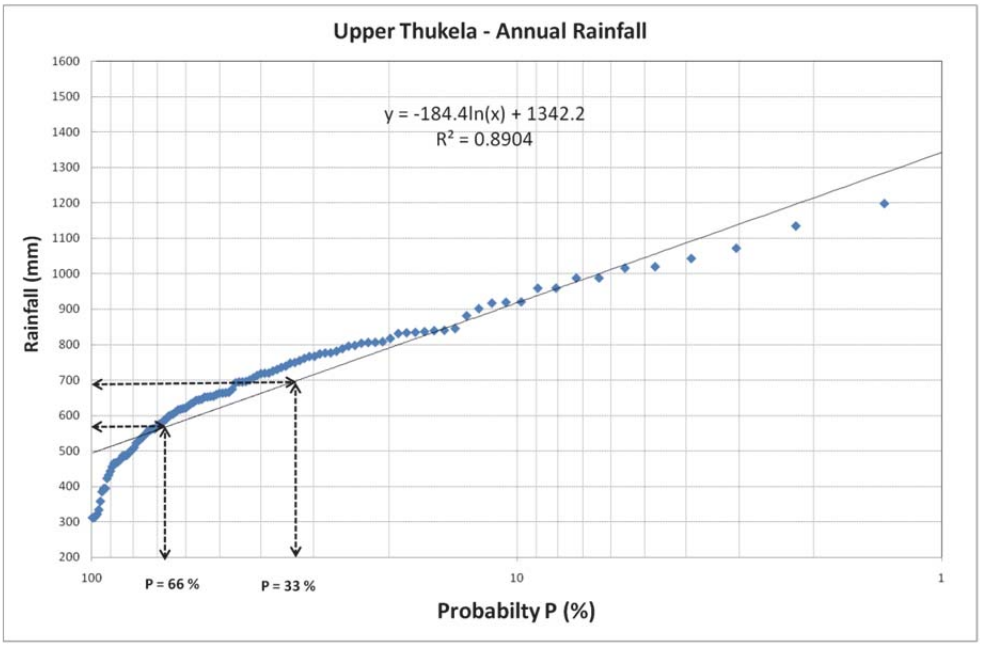


Figure 2-6: Probability diagram with regression line for an observed series of annual rainfall totals Upper uThukela.

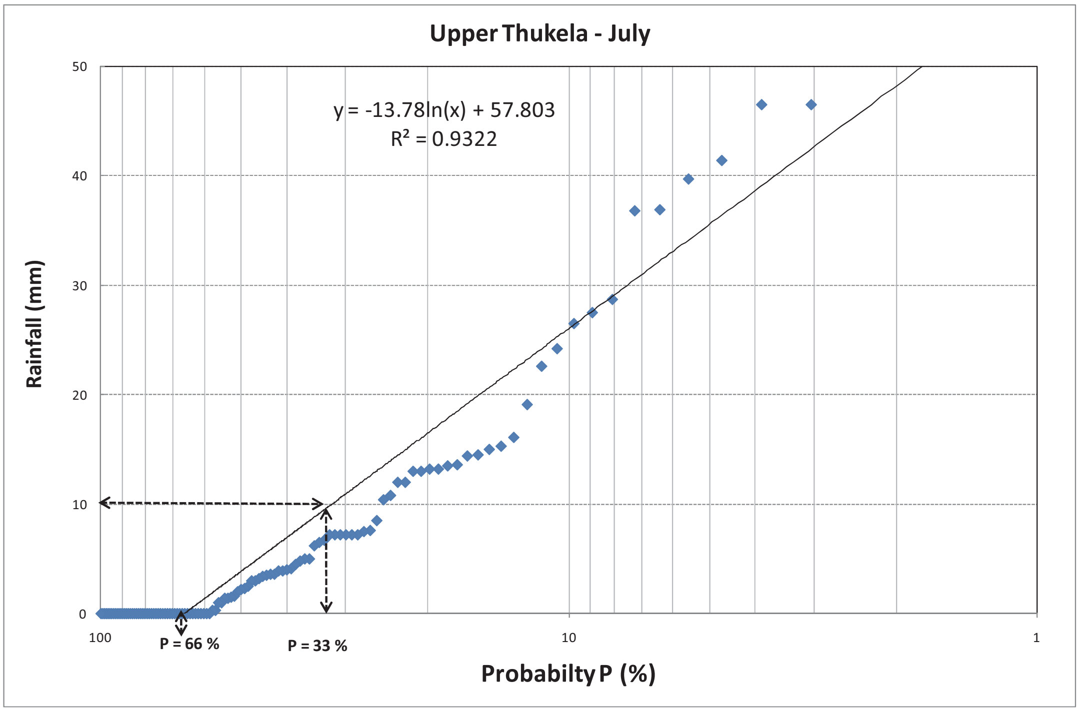


Figure 2-7: Probability diagram with regression line for an observed series of July rainfall totals Upper uThukela.

2.5 RAINWATER HARVESTING RECOMMENDATIONS

To implement RWH techniques for domestic use for operating biodigesters the following procedures should be followed:

1: Map the homestead including potential roof top areas

2: Carry out a design rainfall analysis to determine the roof top area and size of RWH tank to collect enough water to run the biodigester.

3: Use Denison et al.'s (2011) technical manual on RWH to select the most appropriate RWH technique.

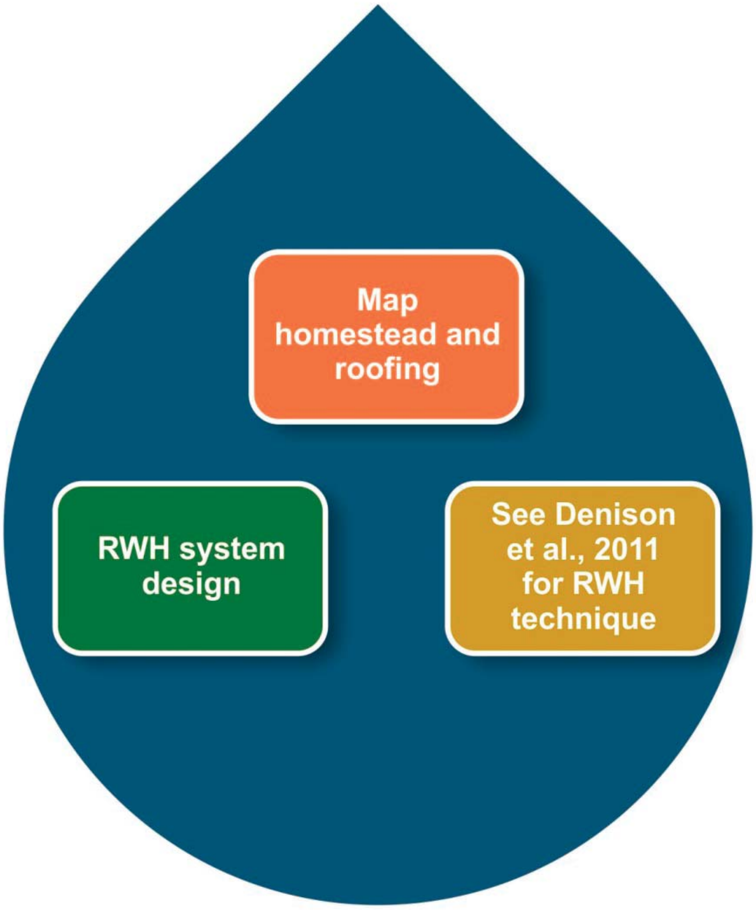


Figure 2-8: RWH recommendations.

CHAPTER 3: GUIDELINES FOR COMMUNITY ENGAGEMENT

Authors: Everson T and Smith M

3.1 INTRODUCTION

The success of a project is dependent largely on the support it has from the community in which it is situated. The 'community' in this sense, is a term that is used broadly to include the (i) local government authority, (ii) the tribal authority, (iii) the leadership and people of the community or village itself.

The process undertaken for WRC project K5/195 proved to be highly successful, albeit for a smaller research based project. Although the engagement process could be approached in many ways, that of WRC K5/1955 is presented here (Figure 3-1) and the steps enacted were as follows:

Step 1: Clearly define the project to be implemented, and prepare a presentation of all necessary details for the engagement process.

Step 2: Engage with local government authority, ensuring that they provide the permission to proceed with the project.

Step 3: Engage with the appropriate tribal authority, ensuring that they provide the permission to proceed with the project.

Step 4: Engage the 'Induna' and elders of the community/village, requesting their support of the project.

Step 5: Develop a household selection criteria, and implement community workshops to (i) inform the community of the project, (ii) allow the community to participate in the selection process.

Step 6: Conduct site visits to selected households, to ensure that all selection criteria are adequately met.

Figure 3-1: Process of initial community engagement.

3.1.1 Step 1: Project definition and planning

Before engaging with the respective authorities and the likely affected parties, it is critical that the project is clearly understood by the project implementers. If the project is being initiated in unison with the authorities, then this process would naturally differ to include them in the project planning.

Although the plan should be open to suggestions from the affected parties, it is important that the implementers understand fully the implications of their project so that they can address any concerns or queries. The items listed above (under 3.3. Project implementation) are all important considerations, and most notably, the implementer should be able to answer questions of project scale and financing models. The presentation of a graphical project plan and timeline (Figure 3-2) or a Gantt Chart (Figure 3-3) is useful in explaining the project process clearly at necessary presentations.

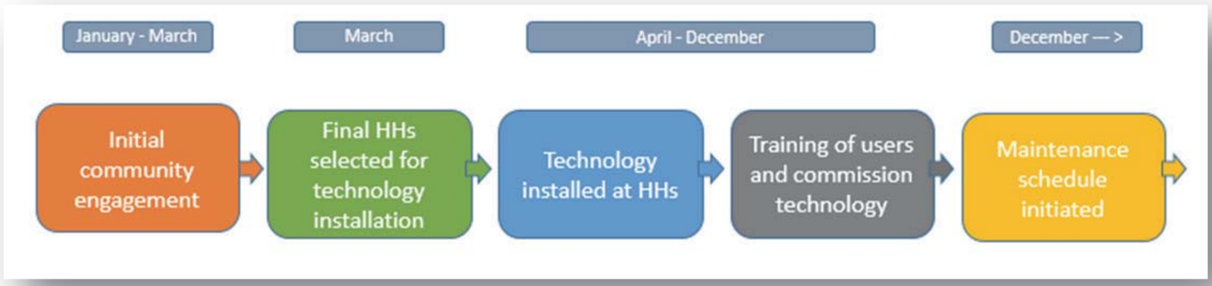


Figure 3-2: Example of graphical depiction of project timeline.

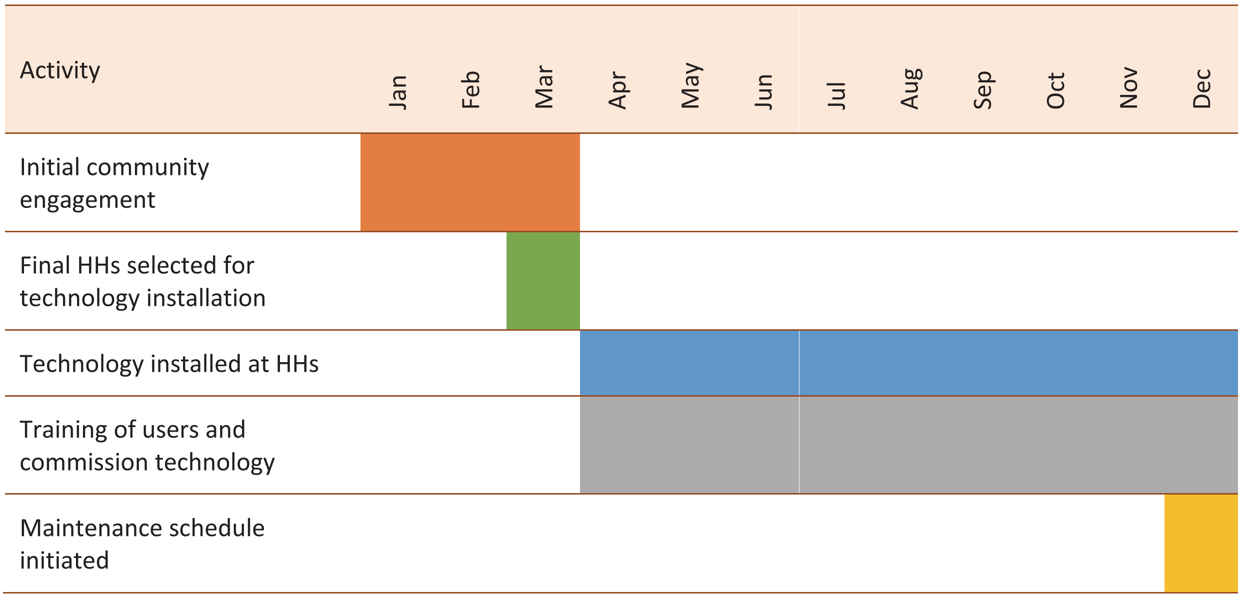


Figure 3-3: Example of Gantt chart for project timeline.

3.1.2 Step 2: Local authority engagement

It is debateable whether the local government should be engaged with before local tribal authority, or *vice versa*, as these groups can have differing perceptions about who is in charge. In order to avert a clash of power or a potential issue here, it is advised that the two be contacted as closely as possible (even simultaneously if a good relationship exists between them).

Engaging with the local government is important, as a biodigester project can be seen as a 'service provision' initiative, and the local government is generally responsible for service provision. The local government may wish to be involved with the project, and in many cases can assist by providing some means of technical aid (e.g. a municipal water truck for biodigester filling).

3.1.3 Step 3: Local tribal authority engagement

Tribal authority engagement, although not always bound by any legal requirement, is an act of good faith which is highly important. Acceptance of a project, and a vote of support for it, from the tribal authority, can make working in a rural area far easier and in some cases safer. The tribal authority is intrinsically connected to the 'leadership' in a village or community, and having their combined support is considered, in our opinion, to be a prerequisite for a successful project.

Depending on the community in question and their standard protocol, the chief of the area needs to be presented with a description of the project and a request to continue the work in the area. In some cases, project developers must 'present their case' in front of the tribal court.

3.1.4 Step 4: Engage with the leadership of the community

The success of the project is dependent largely on the acceptance from the community, and this starts with support from the leaders or elders of that community. Once tribal authority support has been secured, the leaders of the local community should be engaged with. Having support from the tribal authority, and some direction of who to include in this stage of the process, is helpful in this step.

The engagement with the community leaders should follow a similar form, albeit less formal, than that of the tribal authority meetings. A presentation can be given to the community leaders and they can be asked for suggestion on how to undertake various aspects of the project (Plate 3-1). The community leaders will likely play an integral role in the selection of appropriate households, and therefore they can be asked for their suggestion of how to go about this part of the process.

Plate 3-1: Dr Terry Everson meets with a group of interested and respected parties at a Okhombe community before initiating WRC project K5/1955.

3.1.5 Step 5: Household selection process

In the case of a project where biodigesters are going to be donated, in full or in part, to households, it is necessary to ensure that this delivery is done as equitably as possible. This is a difficult task, especially considering that cattle owning households (potentially more wealthy families) are likely to meet the suitability criteria, as cow or other animal dung may be required for successful operation of a biodigester (unless another technical model is being applied).

If biodigesters cannot be supplied to all households in a village, then it is especially important that the community assist in selecting those who will get the technology, and also that it is generally perceived throughout the community that they were responsible for the choices made.

This step is a very important one and is therefore discussed in more detail under Section 3.2 (household selection).

3.1.6 Step 6: Site visits to selected households

The final step before continuing with the installation phase of the project is to conduct actual site visits to the selected households (Figure 3-4). This process may vary, as with all necessary actions, depending on the specifics of the project, financing and inclusion models being employed.

During this stage, it is important to ensure that:

1: The household wants a biodigester.

2: The household is willing and physically able to run a biodigester (and also that they understand all that this implies).

3: The household meets the necessary suitability requirements (see Section 3.5.1) to have and successfully run a biodigester.

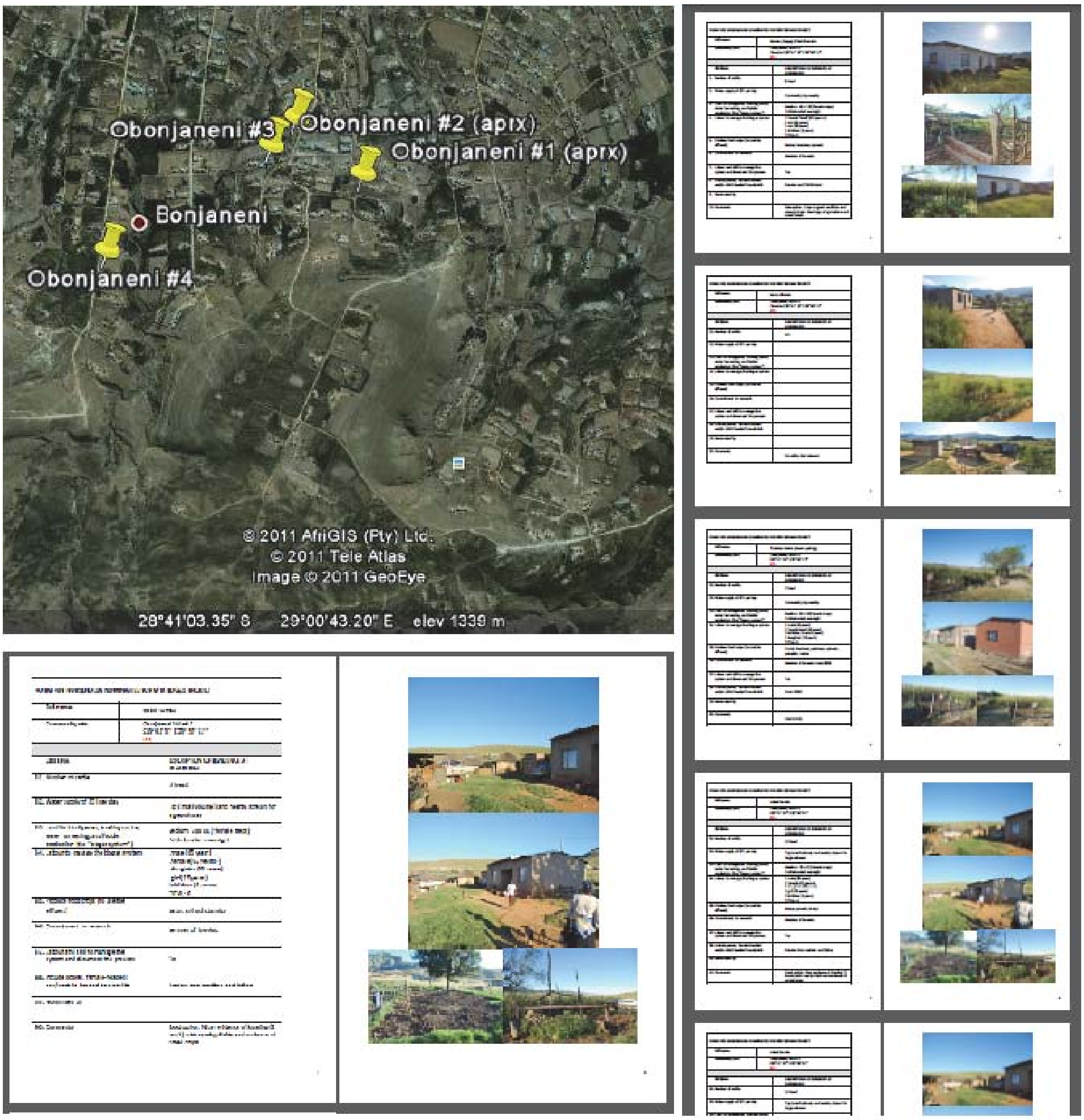


Figure 3-4: Site locations, authenticated nomination forms, site visit reports and pictures for the site selection process at Okhombe, KZN.

3.2 HOUSEHOLD SELECTION

The selection of households for installation of biodigesters is highly dependent on the nature and scale of the project. A private investment initiative, where households purchase biodigesters, is naturally different from a project which involves the donation or subsidisation of the installations.

The vastly differing processes that would be required in varied cases have not been experienced by the WRC K5/1955 team, and therefore we present here the empirical experience and success of the household election process enacted for the installation of pilot digesters at four households in the KZN study site. It should be understood that this process relates to a research project installation, requiring households to be involved with practical aspects of the research. The experience, none-the-less, can provide suitable lessons and guidance for application in scaled-up scenarios.

The model of household selection is broken into four stages here, and they are as follows:

- Stage 1: Developing selection criteria.
- Stage 2: Community meetings.
- Stage 3: Shortlisting of households and site visits.
- Stage 4: Final selection, leadership acceptance and notification.

3.2.1 Stage 1: Developing selection criteria

The successful operation of a biodigester requires that a number of physical/technical attributes be in place at a household. Most prominent of these is that the household needs suitable organic waste of sufficient quantity and enough water to feed the biodigester. It is also necessary that these items be easily collectable.

Although many wastes can be chosen, WRC project K5/1955 chose to explore the use of cattle manure for anaerobic digestion. This choice was made as many rural households own cattle, cattle dung is a very suitable waste for anaerobic digestion, and cattle dung can easily be collected from kraals (amongst other reasons.

As a result, the following selection criteria were defined:

1. **Household must have four cattle, kraaled overnight in a kraal near to their home**
    - Four cattle can produce enough waste (approximately 20kg) overnight to be used in a 6 000 litre biodigester and produce enough gas for a four to five person household (still to be authenticated by remote monitoring, see Case study 4.12).
2. **Access to 20 litres of water per day (waste or fresh water)**
    - Depending on the substrate being fed to the digester, various quantities of water must be added to aid the liquidity of the digestate and promote fluid movement through the digester.
    - A 1:1 mixing ration (cow manure:water) was advised as the appropriate mix for successful operation of the chosen technology (this ratio proved to be questionable during colder months, where it became necessary to add more water.
3. **Sufficient land for all necessary activities**
    - In this case, the requirement included land for (i) the biodigester to be installed, (ii) kraaling of cattle, (iii) food/fodder production – for experimentation trials.

4. **Labour to manage the biodigester**

   - A biodigester requires constant and consistent management. It must be fed with 20kg of cow manure (or other waste) and 20 litres of water per day.

5. **The household was required to be producing food/fodder crops**

   - This was a requirement so that the bioslurry could be used as a liquid fertiliser on these crops, and in this case proved that the household had some interest in farming.

6. **Commitment and ability to aid with research**

   - As a research project, it was required that households either had a proven track record with research projects or were willing to become involved in this process.

   - The households were required to document biodigester operation and biogas use, and it was therefore required that at least one member could fill out a simple record form.

7. **Inclusion of poorer, female-headed and child-headed households**

   - This requirement was included for research purposes, to test the success of the technology implemented at marginalised homes.

3.2.2 Stage 2: Community meetings

Following the development of selection criteria, community meetings were organised with the help of the community leadership and previous groups/people involved with research projects. During these meetings, the attendants were first introduced to biodigester technology and educated about the way it works and the application it can serve at rural households.

Once the technology had been introduced, the attendants were told about the project to be implemented in their areas and asked for their assistance in selecting pilot households for the introduction and testing of the technology.

The attendants were told of the selection criteria and asked to think of households that would be suitable as pilot research sites for the project. They were further given nomination forms (Figure 3-5). An incomplete nomination form from the household selection process) which included an explanation of the project, and a section to be completed for the nomination and motivation of a particular household as a potential site. It was stressed at the meeting that a follow-up site visit would be conducted to authenticate the statements on the nomination forms, and the final decision would need to be made by the researchers, with acceptance from the community leadership. The need for the researchers to make the final decision was motivated by an explanation that varied study sites would be required to, and would aid in, validating the research undertaken through the project.

Attendants were asked to return to another meeting some weeks later, or to send their nomination forms with someone who was to attend. The nominations were captured by the research team for further assessment.

FORM FOR HOUSEHOLDS NOMINATED FOR WRC BIOGAS PROJECT			
Full name			
Community site		GPS coordinates	
CRITERIA	**DESCRIPTION OF EVIDENCE AT HOUSEHOLD**		
1. 4 head of cattle			
2. water supply of 20 l per day			
3. land for biodigester, kraaling cattle, water harvesting, and fodder production (the "biogas system")			
4. labour to manage the biogas system			
5. produce food crops (to use the effluent)			
6. commitment to research			
7. labour and skill to manage the system and document the process			
8. Sources of income in cash and in kind (include poorer, female-headed and/or child-headed households)			

Figure 3-5: An incomplete nomination form from the household selection process.

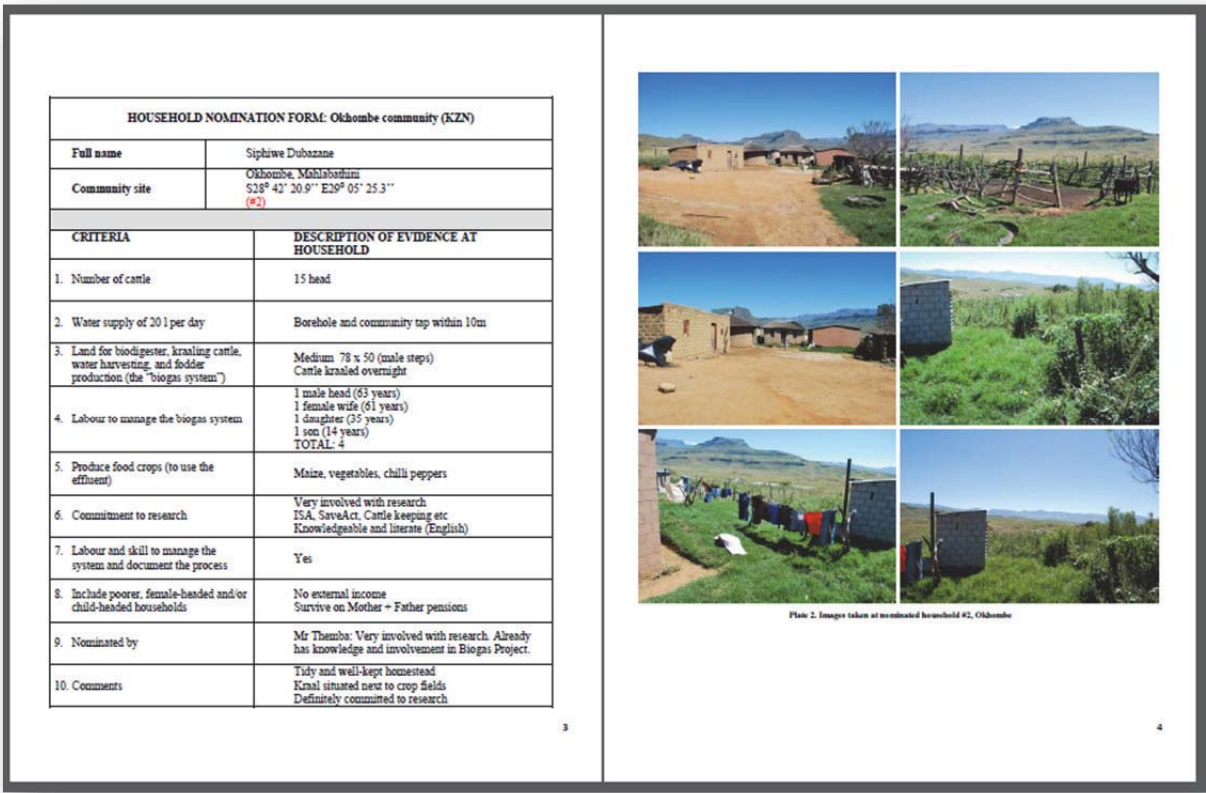
3.2.3 Stage 3: Shortlisting of households and site visits

Following the capture of the nomination form data, the project team carefully assessed the nominated households and selected a number which were potentially suitable and inclusive for research purposes.

A community member and member of the community leadership assisted the project team by informing each of the shortlisted households that a site visit would be conducted on a specific day. This community member also accompanied the project team members on the site visits, and introduced them to the households on arrival. This assistance proved to be useful and important, and undoubtedly aided the team and households in trusting the process that was being undertaken.

The data on the nomination forms was authenticated, and pictures were taken of each site. In addition, the team members intuition was relied on for a general perception of the households, and any relevant observation of household remarks were recorded (e.g. one household member asked what he would be paid to have the system installed at his house).

The authenticated forms, pictures, and observations by the project team members were taken back for further analysis and final decision (Figure 3-6).



HOUSEHOLD NOMINATION FORM: Okhombe community (KZN)	
Full name	Siphiwe Dubazane
Community site	Okhombe, Mahlabathini S28° 42' 20.9'' E29° 05' 25.3'' (#2)
CRITERIA	**DESCRIPTION OF EVIDENCE AT HOUSEHOLD**
1. Number of cattle	15 head
2. Water supply of 20 l per day	Borehole and community tap within 10m
3. Land for biodigester, kraaling cattle, water harvesting, and fodder production (the "biogas system")	Medium 78 x 50 (male steps) Cattle kraaled overnight
4. Labour to manage the biogas system	1 male head (63 years) 1 female wife (61 years) 1 daughter (35 years) 1 son (14 years) TOTAL: 4
5. Produce food crops (to use the effluent)	Maize, vegetables, chilli peppers
6. Commitment to research	Very involved with research ISA, SaveAct, Cattle keeping etc Knowledgeable and literate (English)
7. Labour and skill to manage the system and document the process	Yes
8. Include poorer, female-headed and/or child-headed households	No external income Survive on Mother + Father pensions
9. Nominated by	Mr Themba: Very involved with research. Already has knowledge and involvement in Biogas Project.
10. Comments	Tidy and well-kept homestead Kraal situated next to crop fields Definitely committed to research

3

Plate 2. Images taken at nominated household #2, Okhombe

4

Figure 3-6: An authenticated nomination form along with images taken at a site selection visit.

3.2.4 Stage 4: Final selection, leadership acceptance and notification

The final stage in the selection process first saw a review of the authenticated data and images taken. The project team members attempted to choose households that they perceived to fit all necessary criteria for a successful research site, as well as aiming to get a broad variety of pilot household characteristics.

Once the households had been chosen (Plate 3-2), the community leadership were notified of the final decisions and asked for their approval thereof. The approval was given easily as they had been involved with the process, and understood clearly the needs of the research team.

All shortlisted, including those who were not selected, were notified of the decisions made and the chosen households were visited to secure their agreement. These households were asked to voluntarily sign a declaration of their commitment to the research to be undertaken, and their understanding of all that was involved in the project.

Plate 3-2: A very happy Ethel Khumalo (Obonjaneni pilot study household).

CHAPTER 4: GUIDELINES FOR BIOGAS IN RURAL AREAS

Authors: Smith M, Langley K and Agama Biogas

4.1 INTRODUCTION

The Water Research Commission (WRC) project K5/1955 was initiated in April 2010, with installations of anaerobic biodigesters and rainwater harvesting systems at rural pilot study households in KwaZulu-Natal, Limpopo and the Eastern Cape. The research team's role was to investigate various aspects of these technologies, their integration in the rural household, and their impacts on livelihoods, grasslands and livestock.

Experience by the researchers and pilot study households revealed that the production of biogas from livestock manure is a process which requires suitable guidance, education and modification to accommodate various situations. The optimal running of a biodigester has proven to be important in achieving the identified economic and financial worth, and sometimes challenging, given the novelty of the technology in South Africa and especially rural communities.

Consideration of replicating these technologies on a greater scale reveals the need to both optimise the current processes and guide the progression in a manner that will achieve successful implementation and secure societal benefit. The project has exposed the need to manage this cautiously, ensuring that community engagement, area specific technological adaptation, education and training are shepherded by a practical experience informed process.

This report relates specifically to the application of pre-fabricated tank biogas digesters (the Agama BiogasPro) in a rural South African setting (Plate 4-1). The report also presents an outline of biogas, biodigesters, and project implementation. Although much of the technical detail relates to a specific design and type of biodigester, the content is applicable to many other applications of anaerobic digestion in both an urban and rural domestic context.

This guidelines report is intended for public use with a wide ranging readership. The document is written as succinctly as possible, with an attempt to minimise complex academic and scientific writing. The intention herein is to provide a simplified and accessible reference manual for implementing a rural biogas project in South Africa.

Plate 4-1: A biodigester and biogas flame at a WRC K5/1955 pilot household in KwaZulu-Natal.

4.2 THE BASICS OF ANAEROBIC DIGESTION

Anaerobic digestion is the process in which biogas is made. Quite simply, it is the biodegrading of organic material under the absence of oxygen. To achieve an oxygen free environment in which the organic material can be digested, various types of biodigester (also called biogas digesters, anaerobic digesters, or digesters) are used. The products of anaerobic digestion are biogas and bioslurry.

In this section, we will discuss the basic process of anaerobic digestion, the types of biodigesters, and the characteristics of the anaerobic digestion products (biogas and bioslurry).

4.2.1 Anaerobic digestion and suitable feedstock

Anaerobic digestion is the process of breaking down organic material under the absence of oxygen. Anaerobic microorganisms (tiny bugs that live in oxygen free environments) grow within the digester and eat away at the organic matter. There are various stages of the process that take place within the digester and at each of these stages different colonies of organisms exist. The detail and chemistry of these stages is highly complex and the manner in which it takes place is dependent on tank specific variables, including: temperature, tank design, and organic waste type. Figure 4-1 displays a model of the likely interactions across this process.

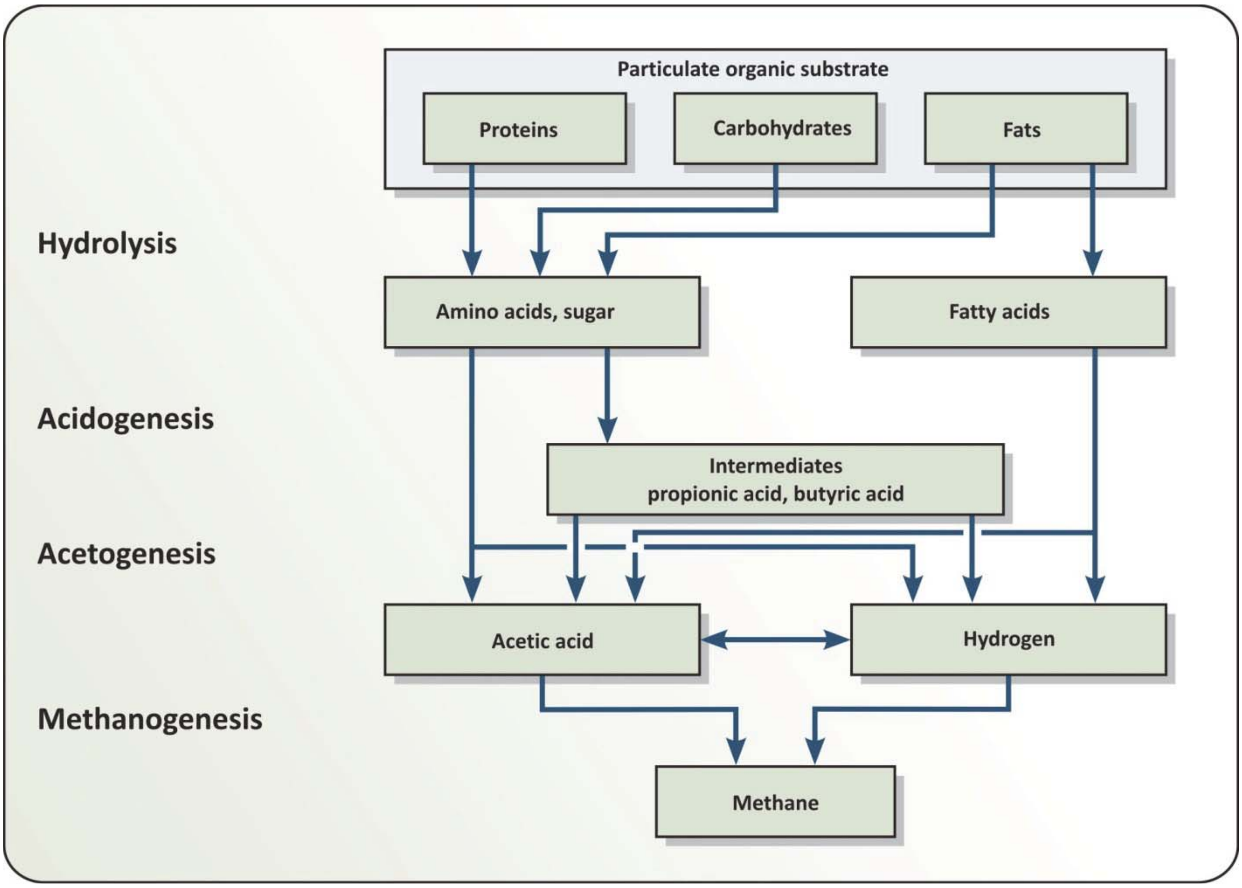


Figure 4-1: The four stages of the anaerobic digestion process (source: Serna 2009).

The waste that is fed into the digester is called 'feedstock' or 'substrate'. When it is in the tank, we call it digestate, as it is the material that the anaerobic microorganisms are digesting. Essentially any organic matter can be fed into a digester, however, one must apply common sense in deciding whether substrate will be easily digested or not. If it is plausible that an animal (a cow for example) could eat and digest the substrate, or has done so already (manure), then it is probably an appropriate material.

4.2.1.1 Good waste to start the anaerobic digestion process

It is often advised that animal manure (e.g. cow manure) should be added to a small-scale digester to start the anaerobic digestion process. Animals' stomachs are full of the type of bacteria that are needed for waste digestion and by adding their manure to the digester, the anaerobic digestion process can be 'kick-started' into action.

4.2.1.2 Typical wastes/feedstock for domestic anaerobic digesters

Animal manure and non-woody organic material are good substrates for anaerobic digestion. By non-woody, we mean fruit and vegetables (kitchen waste), grass clippings, and even meat waste. Woody waste, like branches and thick stalks, is not appropriate for anaerobic digestion. Although this material can be broken down by the microorganisms, it would take a long time as it is tough and difficult for them to do so. Materials like dry manure and straw are also not appropriate wastes. They tend to have very few nutrients left in them and are also difficult to break down, so they will produce very little biogas and will possibly block the system.

Cleaning agents with antibacterial properties should never be put in a digester as they are designed to kill microorganisms and will therefore kill the good bugs that are digesting substrate and making biogas. Products like bleach, toilet cleaner, drain cleaner and de-steriliser should not be added to a digester.

Table 4-1 presents some of the items that can and some that should not be added to an anaerobic digestion (extracts from Agama, 2010). The rate and variation of adding substrates is discussed below.

Table 4-1: Good and bad feedstock for a biodigester.

GOOD FEEDSTOCK		
Manure	Cow, pig and chicken manure. Manure is rich in bacteria and a highly suitable feedstock. Manure should be loaded when it is fresh, and one should avoid loading manure that is contaminated with sand, grit, straw or animal bedding.	✓
Kitchen scraps	Kitchen scraps (vegetable waste) is high in energy. Scraps should be chopped as finely as possible to promote fast digestion (i.e. greater surface area for bacteria).	✓
Garden waste/off-cuts	Grass cuttings and other non-lignin garden wastes can be used and have a very high energy content and biogas yield. Grass cuttings should be pre-digested/silaged for four to six weeks, if possible.	✓
Human waste*/sewage	Sewage from flush toilets typically has high water and low solids, and is therefore a relatively low yield feedstock. Grey water (bath, shower, basin water) should be separated from black water (toilet and urinal water), and only the black water should be directed to the biodigester.	✓
Agricultural waste and energy crops	Energy crops and agricultural waste can be high yield wastes for a biodigester. Loading limits should be adhered to carefully and the feedstock should be macerated to < 2.5mm pieces.	✓
BAD FEEDSTOCK		
Chemical compounds	Bleaches, acids, weed killers, paints, thinners, heavy duty cleaners, photographic chemicals, engine oil, brake fluid, anti-freeze, and other non-biodegradable chemicals. These chemicals can kill the anaerobic bacteria.	✗
Organic materials	Sand, wood, branches, high lignin leaves, sawdust, feathers, bones. These compounds will likely build up in the system, reducing its capacity and/or causing blockages and failure.	✗
Inorganic materials	Plastic, glass, sanitary pads, nappies and cigarettes. These items and other inorganic wastes will block the system and potentially cause failure.	✗

* Human waste is an appropriate waste for anaerobic digestion and therefore digesters can be connected directly to a toilet or pit type latrine. It is not, however, advised that human waste be used in a digester if the bioslurry is going to be used as a fertiliser for growing vegetables or crops. Human waste carries pathogens which can make people sick if they come into contact with it. If human waste is going to be used, and the bioslurry is to be used for growing crops, then a microbiologist should be consulted and a process by which the bioslurry can be desterilised can be put in place. The process of doing this can be expensive and energy intensive, and should be considered carefully before application. It should also be considered that some people and cultures do not like using human waste for growing food or even for cooking (using the biogas).

4.2.2 Types of small scale biodigesters

Biodigesters vary greatly in size, from small scale home/domestic units, to farm scale digesters for processing of animal and agricultural waste, to industrial/utility scale digester for processing large quantities of organic waste (often the organic fraction of municipal solid waste).

This report presents a few of the small scale biodigester options that are used at household level. We present here some common types of biodigesters, but it is noted that thousands of variations exist.

4.2.2.1 Tube digester

A tube digester (Figure 4-2) is usually made out of polyethylene (plastic) sheeting, and is known to be the lowest cost anaerobic digester (Table 4-2). Tube digesters are often referred to as 'plug flow digesters' as the waste is inserted at one end, flows through the tube, and exits at the other end (Plate 4-2). Both of these ends are plugged to keep them air-tight. The waste is either pushed along as new waste is inserted or can be agitated and forced along by a mechanical system.

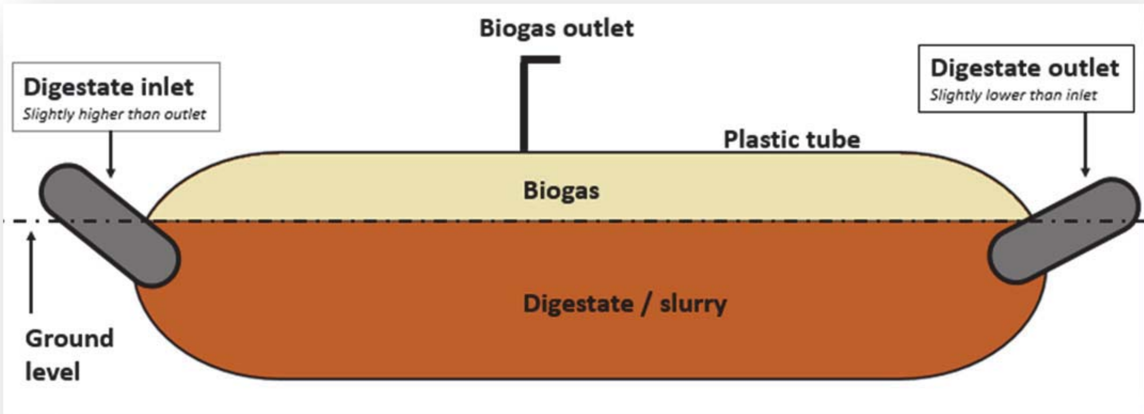


Figure 4-2: Cross-sectional diagram of a tube digester

Plate 4-2: Various tube digester installations – style and size can vary greatly (source: Energypedia 2010; Weatherford, 2010)

Table 4-2: Tube digester characteristics and information

Typical use	For small households and subsistence agriculture
Typical feedstock	Food waste and animal waste (cow, pig, chicken)
Construction material	Polyethylene tube / sheeting
Positives	• Low cost • Simple construction • Low depth of build suitable for areas where ground water level is high • Ease of transport
Negatives	• Highly susceptible to temperature changes[1] and therefore only appropriate in warm and temperate areas with minimal temperature variations (over night or across seasons) • Short lifespan of materials, and balloon top is vulnerable to damage • Local tradesmen are unlikely to have skills to repair tube leaks • Relatively inefficient in processing waste and generating biogas

4.2.2.2 Fixed dome digester

A fixed dome digester is usually a tank that is constructed underground using brick and mortar (Plate 4-3). These tanks have an underground storage area, a feeding chamber, an outlet chamber, and a dome (above or below ground) which is used to capture the gas. Gas pressure is usually created by digestate levels in the inlet and outlet chambers (as in Figure 4-3). As gas is used, the digestate fills its place, and the pressure reduces. Although implementation of this digester can result in income generation for community members, it is expensive to construct (Table 4-3).

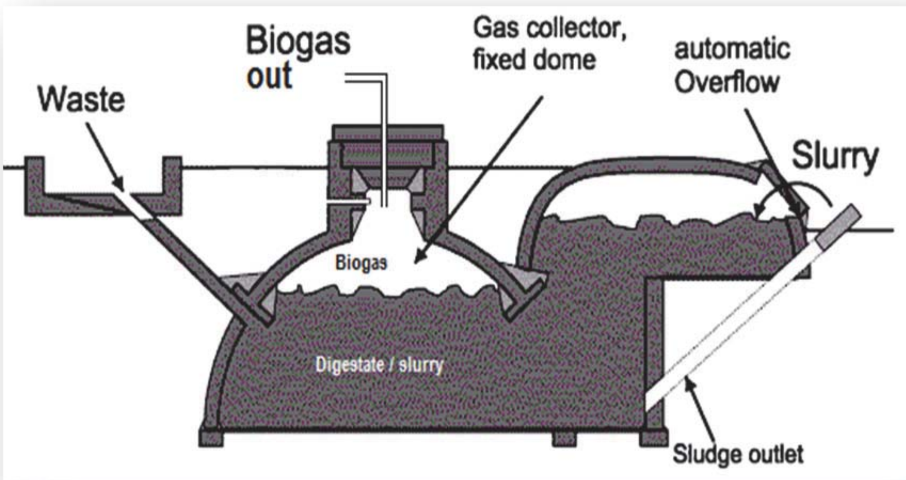


Figure 4-3: Basic design of a fixed dome digester (adapted from: Energypedia 2009)

[1] The microbials in a digester perform best under constant conditions. Changing temperatures can kill bacteria and reduce production of biogas. Fluctuations from cold to hot are very bad for a biodigester system.

Plate 4-3: A fixed dome digester during construction and near completion (source: Tangka 2010; Lebofa 2006)

Table 4-3: Fixed dome digester characteristics and information

Typical use	For small households and subsistence agriculture
Typical feedstock	Food waste, human and animal waste (cow, pig, chicken)
Construction material	Brick and mortar
Positives	• Below ground and brick/mortar construction maintains tank temperature • Materials are readily available • Tank is below ground and therefore non-obtrusive • Typically long lifespan if constructed well
Negatives	• Expensive to construct • Soil, earth, water conditions need to be considered in construction • Construction requires higher level of expertise • Once constructed, tank leaks are highly difficult to access and fix

4.2.2.3 Floating dome digester

A floating dome digester (Figure 4-4) is typically very similar to a fixed dome digester in construction, excepting that the dome is designed so that it can rise and fall as gas builds (Plate 4-4). The benefit of this system lies in the fact that a greater volume of gas can be stored in the dome (Table 4-4), and the pressure of the gas can be regulated externally by weighting the floating dome/tank (for example, with bricks or sandbags). It is also easier to remove the dome for digestate tank repairs.

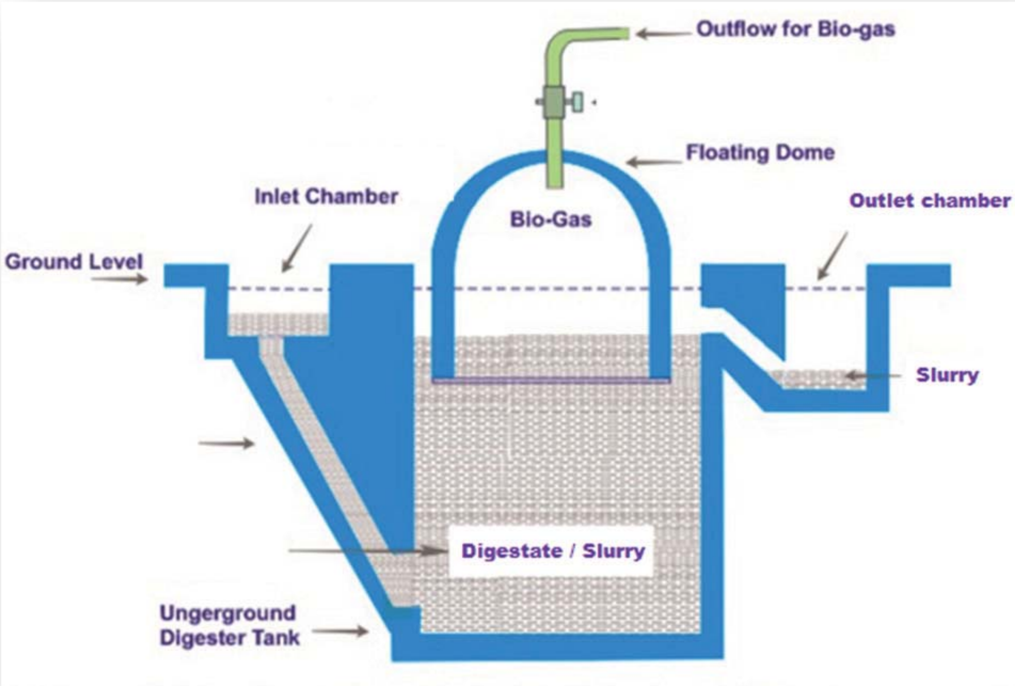


Figure 4-4: Basic design of a floating dome digester (adapted from: Biogas Plant (AD) Blog 2015)

Plate 4-4: Examples of floating dome digesters (source: Biogas Technology 2011; Technology Times 2011)

Table 4-4: Floating dome digester characteristics and information

Typical use	For small households and subsistence agriculture
Typical feedstock	Food waste, human and animal waste (cow, pig, chicken)
Construction material	Brick and mortar with a LDPE[2] (plastic) tank top
Positives	• Increased gas storage and no displacement of digestate as gas pressure rises • Below ground tank leaks can be accessed and fixed more easily by removing tank top • Below ground tank maintains digestate temperature more consistently • Materials are readily available
Negatives	• Gas leaks between bottom and top tanks are common • Construction is more technical and requires experienced builders/technicians • Tank maintenance requirement is typically higher as fluid movement between top and bottom tanks is required

4.2.2.4 Pre-fabricated tank digester

A pre-fabricated tank digester is usually made in a roto-mould with LDPE plastic and is transported to site as a complete unit (Plate 4-5). The benefit of these digesters is that they can be pressure tested at the factory (to identify leaks) and if they are installed correctly, are expected to have a long lifespan (Table 4-5). The pre-fabricated tank digester is considered especially appropriate in rural areas where a relatively hassle free system is required and where little expertise is available for on-site built digesters. Pre-fabricated tank digesters come in a variety of sizes and designs. Project developers should be careful to choose systems that have been tried and tested under local conditions (see Case study 4.1. Agama BiogasPro6 versus Sintex digester).

[2] Low-Density Polyethylene.

Plate 4-5: Agama BiogasPro (left) and Sintex (right) pre-fabricated tank digesters

Table 4-5: Pre-fabricated tank digester characteristics and information

Typical use	For small households and subsistence agriculture
Typical feedstock	Food waste, human and animal waste (cow, pig, chicken)
Construction material	LDPE plastic
Positives	• Factory tested for leaks and faults • Simple installation requiring minimal building materials • Long lifespan of tank • Lesser tank maintenance requirements • Construction can be assured to be according to original design, and therefore this guarantees expected performance • Below ground tank maintains more consistent temperature fluctuation of digestate • Below ground and therefore non-obtrusive
Negatives	• Relatively expensive • Difficult to fix leaks if they do arise from a tank fault or incorrect installation • Gas storage is limited to design specification (this is however quite respectable in the designs that have been seen locally).

4.2.2.5 Combination built digester with pre-fabricated dome

A domestic combination digester comprises of a brick and mortar built holding tank (just like a fixed or floating dome digester [described above in Section 3.2.2.2 and 3.2.2.3]), with a pre-fabricated LDPE (plastic) or fibreglass dome on top (Plate 4-6). The dome of a fixed dome built digester is very difficult to construct, requires experienced artisans, and can be difficult to repair once built. The main advantage of a combination digester is that this dome can be delivered to the site as a factory tested unit, can be installed relatively easily and can be removed if any sub-surface faults emerge (Table 4-6). The bottom slurry reservoir can be built more easily by experienced builders who need not have experience in building anaerobic digesters.

Plate 4-6: A BiogasPro SmartTop digester being installed, the base of tank is built on site (left), the SmartTop is installed and sealed onto the unit (right)

Table 4-6: Combination digester characteristics and information

Typical use	For small households and subsistence agriculture
Typical feedstock	Food waste, human and animal waste (cow, pig, chicken)
Construction material	Brick and mortar slurry reservoir with LDPE plastic or fibreglass dome
Positives	• Bottom reservoir built easily by experienced builders and does not require specialist digester artisans • Top dome can be factory tested for faults and delivered for easy addition to bottom reservoir • Dome can be removed if tank repairs are required • Dome is specifically designed for gas capture and management • Slurry reservoir depth can be varied for different requirements • Structure can be sub-surface for temperature control
Negatives	• Achieving air-tight connection between dome and slurry tank can be difficult • Dome can be relatively expensive, depending on material, design and transport • Leaks in a LDPE dome can be difficult to fix and require experienced technicians • Gas storage is limited to design specification (this is however quite respectable in the designs that have been seen locally).

4.2.2.6 Simple above ground tank digester

Above ground domestic tank digesters come in a variety of shapes, sizes and forms. These digesters are typically low-cost, homemade and have a greatly varying degree of success. These digesters are commonly constructed out of simple plastic tanks, either single or in series, and capture gas in a separate tank, bag or tube (Plate 4-7). Feedstock typically consists of domestic kitchen or restaurant waste. The nature of the materials used and above ground placement of the tanks means that the digester is highly susceptible to external temperature conditions and is therefore only appropriate for consistently warm climates (Table 4-7).

Plate 4-7: Various simple tank digesters (source: Burton 2014; Antoniraj 2015)

Table 4-7: Simple tank digester characteristics and information

Typical use	For small household processing of waste
Typical feedstock	Food waste
Construction material	LDPE plastic or other tank
Positives	• Cheap, simple construction • Can be handmade in a variety of ways • Is typically modular, so more tanks can be added for increasing waste disposal • Appropriate for controlled small-scale lab testing of various wastes as anaerobic digestion substrates
Negatives	• Highly susceptible to external temperature conditions • Unless the system is controlled and fed with great consistency, these systems tend to be inefficient • Rudimentary and often unsuccessful

4.2.2.7 Gas storage

The storage and transport of biogas in domestic settings can be difficult. Often domestic biodigesters have a very limited gas capacity, and if the gas is not used, it is vented into the atmosphere. Biogas, made up predominantly of methane (CH_4), is a powerful greenhouse gas, and this is therefore a negative outcome.

The best, and most effective, method of averting the loss of biogas into the atmosphere is to use it on a consistent day-to-day basis. Flaring gas (burning it) is another mechanism of preventing this outcome, but requires some technical equipment to be in place and also raises some safety concerns.

Options do exist for gas storage. The most simple of these methods is to tap the gas directly into tractor tyres, or specially made plastic bags (Plate 4-8). Once the gas is stored in these capsules, it can be transported and used elsewhere. The difficulty of using this gas is that it requires pressurisation. Small, motorised gas pumps can be used. Sometimes, this pressure can be delivered by weighting the capsules with heavy materials, or even by having someone sit on the capsule. The difficulty of this is that the correct pressure can be difficult to achieve, and obviously changes as the capsule empties.

Plate 4-8: Tractor tyre tubes (left) or specifically designed biogas storage bags (right) can be used for gas storage (source: Linea Tyre n.d.; Takamoto Biogas 2011)

4.2.3 Products of anaerobic digestion

There are two primary products that come from the process of breaking down waste in an anaerobic digester. These products are biogas and what we will call bioslurry (also called digestate, slurry or sludge). The nature and composition of these products varies and is dependent on the type of waste that is being digested, the design of the digester, and the conditions under which the anaerobic digestion takes place (e.g. temperature).

4.2.3.1 Biogas

Biogas is a product of anaerobic digestion and is made up predominantly of methane (CH_4) and carbon dioxide (CO_2) in varying ratios. For biogas to be easily combustible it is necessary that at least ~50% of the composition be made up of CH_4, as this is the flammable gas in the mixture. Table 4-8 displays the typical composition of biogas from 'traditional methods' / small-scale domestic biodigesters (Angelidaki et al., 2013).

Table 4-8: Biogas composition

Compound	Formula	Percentage of total (%)
Methane	CH_4	55-75
Carbon dioxide	CO_2	25-50
Nitrogen	N_2	< 5
Hydrogen	H_2	< 1
Hydrogen sulphide	H_2S	< 0.5
Ammonia	NH_3	< 0.05
Oxygen	O_2	< 2

The composition of biogas can vary greatly, and is largely dependent on the substrates that are being fed into the digester. As a result of these changing characteristics of the gas (Plate 4-9), the energy content (called 'calorific value') of the biogas also varies. Table 4-9 presents the typical characteristics of raw biogas, concentration of 60% CH_4 and 40% CO_2 (Angelidaki et al., 2013).

Plate 4-9: Biogas bubbles forming on the top layer of digestate in a biodigester

Table 4-9: Biogas characteristics

Biogas (60% CH_4 and 40% CO_2)	
Calorific value	21.53 $MJ.m^3$
Ignition temperature	650-750°C
Normal density	1.20 $kg.m^3$
Molar mass	27.23 $g.mol^1$

Plate 4-10: Biogas flames at a WRC K5/1955 pilot household

As a flammable gas, biogas is a useful product that can be used for a variety of applications (Table 4-10). In large scale production, biogas is usually used to make electricity in gas fired engines, heat large industrial boilers, and even used as a fuel in natural gas converted vehicles (e.g. busses, trucks, cars). At small scale domestic operation, biogas can be used for cooking, heating, lighting, refrigeration and can also be used to power small electrical generators. The most practical and simple use of biogas is for cooking (Plate 4-10), as this requires simple, cheap technology and is one of the most efficient means of using the product.

Table 4-10: Typical efficiencies for appliances using biogas (source: Al Seadi 2008)

Biogas appliances / uses	Efficiency
Heaters	88%
Stoves	55%
Internal combustion engines	24%
Lamps	3%

4.2.3.2 Bioslurry or digestate

Bioslurry, digestate or slurry is digested matter that exits the biodigester after the anaerobic digestion process. The bioslurry is typically a liquid substance of similar consistency to a thick soup (Plate 4-11). The composition of the bioslurry is entirely dependent on the biomass substrates that have been fed into the digester, and the degree to which they are broken down by anaerobic digestion bacteria is relative to the design of the digester, the length of time it has been in the tank (the 'hydraulic retention time') and the optimality of the conditions in the tank. It is often thought that most of the nutrients and mass of the digestate will be 'lost' in the form of biogas, however, less than 5% of the mass becomes biogas and the useful nutrients remain. We should remember that biogas is made up mainly of CH_4 and CO_2 and therefore it is mainly Carbon (C), Hydrogen (H_2) and Oxygen (O_2) that have 'escaped' the digestate as biogas.

It follows that all the useful nutrients that were first fed into the digester remain in the digestate / bioslurry, and can therefore be used usefully as an organic fertiliser. The Nitrogen, Phosphorus, and Potassium (N, P, K respectively) that entered the system, will come out in a useful liquid form which is also carbon rich.

Although the WRC K5/1955 project team is still researching the benefit of using bioslurry as an alternative to chemical fertilisers, literature suggests that bioslurry has many positive properties as a fertiliser and should improve soil conditions and plant growth. It should be remembered, however, that the quality of the slurry is directly proportional to the quality of the matter that is fed into the digester.

Plate 4-11: A young boy pouring liquid digester slurry/digestate onto a vegetable garden at a pilot household

4.3 PROJECT IMPLEMENTATION

Although implementation of a rural biogas programmes have been conducted around the world, the concept is relatively unexplored in South Africa. WRC project K5/1955 has researched the implementation of pre-fabricated anaerobic digesters at dissociated homes, schools and communities in Limpopo, the Eastern Cape, and KwaZulu-Natal (Figure 4-5). From this experience, the project aim is to guide future, large scale roll-outs of biodigesters.

Some of the questions that need to be asked before spending further resources on a large scale project implementation are:

1. What is the scale of the project to be implemented?
2. For who is this project being implemented, and how best can the technology serve their interest?
3. Is this technology the most suitable option for the inhabitants of the affected area, or could other technologies serve their interests more efficiently and/or economically?
4. Who will be responsible for the critical training and maintenance components of this project? Will the technology be maintained after project implementation?
5. Who is the financier of the project and what financing model is being employed?
6. Is there local government and tribal support for the project?
7. Has the community been engaged with and are they 'on-board' with the project concept?

These are important questions which need to be asked in order to guide the manner in which the project continues.

4.3.1 The context of this report

In the sections to follow, guidelines for project implementation of biogas systems for rural areas will be defined. Although this 'manual' and the lessons learned in implementing WRC project K5/1955 serve great purpose in guiding a variety of biodigester projects, they should be read within the context of the project – and extrapolated *in accordance with this recognition*.

WRC project K5/1955 is a five year Water Research Commission project which has explored the application of biodigesters in rural areas of South Africa for the provision of energy and bioslurry for food and fodder crop production. The project involved the installation of four Agama BiogasPro6 digesters in KwaZulu-Natal (at rural households), three BiogasPro6 digesters in Limpopo (at farming co-operatives and school crèches, and two BiogasPro, one Puxin Sintrix and two BiogasPro SmartTop digester in the Eastern Cape (at rural households).

Figure 4-5: Locations of WRC project K5/1955 research sites

Various aspects of these implementations where investigated through the project, with specific research into the technical, financial and social viability of the technology for rural application. Following these experiences, this report presents guidelines on the experiences and is based largely on the application of the Agama BiogasPro6 prefabricated tank digester. This digester proved to be the most successful of those implemented, and is believed to be a viable option for large scale project roll-out in South Africa.

4.4 BIOGASPRO INSTALLATION – TECHNICAL MANUAL

It has been noted that many differing types of biodigesters exist, and even in the case of pre-fabricated tank digesters, it is likely that their installation would be different. We include here an adapted version of the technical installation instructions for the AGAMA BiogasPro6 (Agama 2010). These instructions, although specific to the BiogasPro, may shed light on the process of installing other pre-fabricated digesters – and can help project developers to understand the intricacies of the process required.

4.4.1 Transport and handling

1: Check for signs of failures on the *BiogasPro* on arrival and before off-loading from the transport vehicle (Plate 4-12).

2: Check and record the serial number of the *BiogasPro*.

3: When moving the *BiogasPro*, avoid sharp objects which could cause a puncture or general damage.

4: To move the *BiogasPro*, always roll it, never drop it; provide a ramp to roll the BiogasPro off any transport vehicle.

Plate 4-12: Biodigester en route to the Eastern Cape and KwaZulu-Natal

4.4.2 Tank installation

1: The location of any underground services should be known prior to installing the BiogasPro.

2: Select a site with good sub-soil drainage and avoid installations in water-saturated clays or areas with a high water table.

3: Choose a site so that the BiogasPro will be positioned in a place where:

- There is ready access for plumbing.

- It is at least 3 metres away from any building or site service.
- It is out of the way of any vehicle traffic.
- It is away from tree roots, over hanging trees and general fire hazards.
- It is as close to the sewer outlet point and gas user point as possible but far enough away from a structure so as not to damage the structure during the tank installation.
- It allows for the incoming sewer pipe to be laid downhill (at a gradient of up to 1:60).
- It allows whenever possible that the gas line runs uphill to the gas user-point. Where this latter gas line configuration is not possible then a condensation trap must be installed at all the low points in the gas line.

4: The BiogasPro must be installed in accordance with SANS 1200 specifications.

5: You would have purchased either the BiogasPro-6 or BiogasPro-6D digester. For the BiogasPro-6, excavate the hole to 3m x 3m x 2.3m deep; for the BiogasPro-6D installation, excavate the hole to 3m x 3m x 2.6m deep. Note that this is the maximum permissible depth of the BiogasPro. (Figure 3-13).

6: Ensure that the base of the excavation is level and well compacted. The depths indicated in (5) above allow for a sand base that must be placed at the bottom of the excavation to bed the tank (Figure 4-6). Do not bed the *BiogasPro* on sharp objects.

7: The above depths will ensure that the sewer pipe entering the BiogasPro is at an invert depth of 330 mm or 600 mm from the natural ground level (NGL), for the BiogasPro-6 and BiogasPro-6D installations respectively.

8: The above depths will ensure that the risers will protrude 30 mm above NGL. They must protrude no less than 30mm and no more than 50mm above NGL.

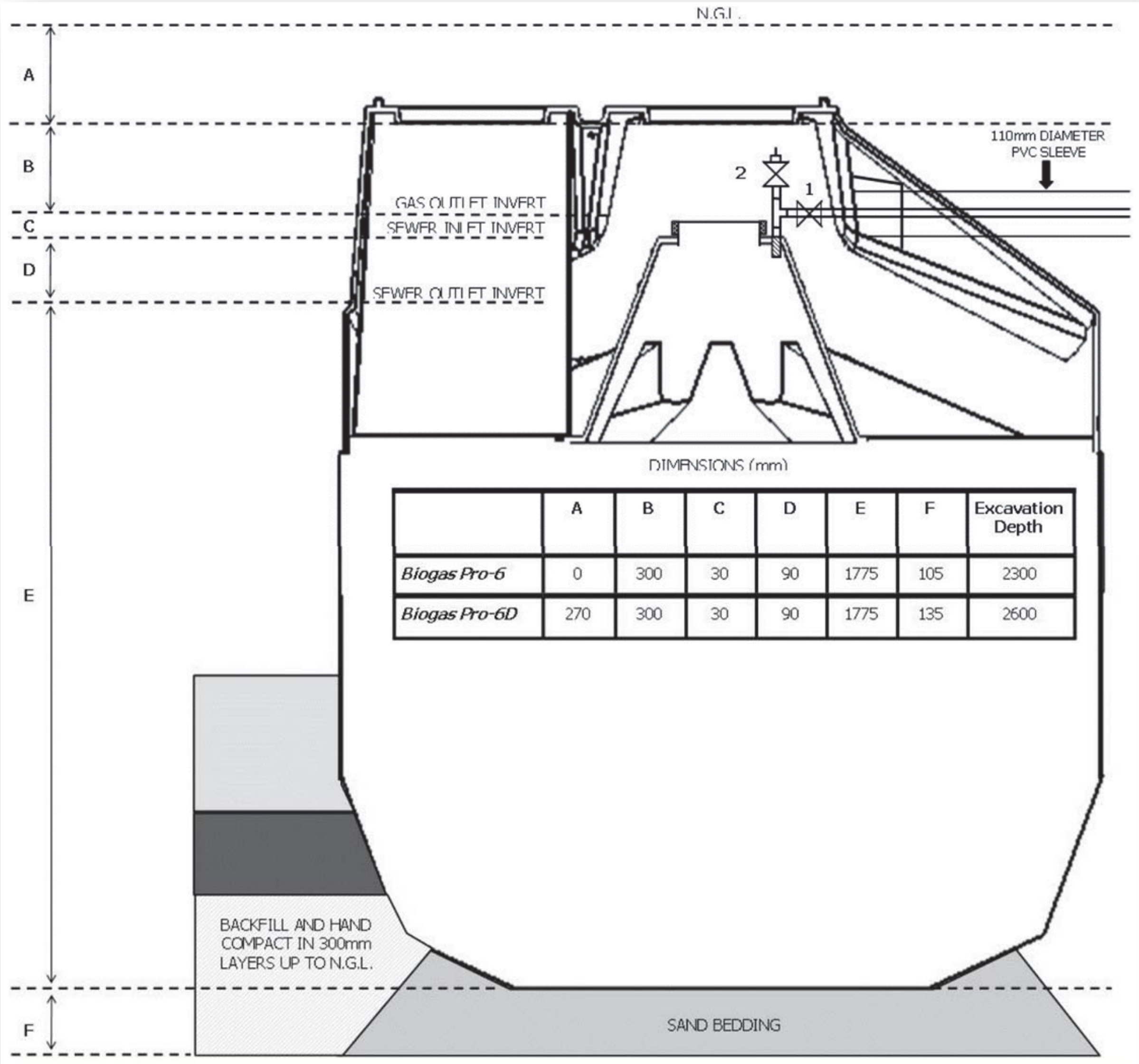
9: If clay, peat or rocky ground is evident, throw a 150 mm thick reinforced concrete foundation in place of the sand bedding below the digester.

10: The BiogasPro must be lowered into position (by use of strops around its base or by ropes attached to the handles). It must never be dropped into the hole. The BiogasPro can also be positioned by sliding it into the excavation. This can be achieved by creating a 45-degree batter to one of the excavated walls and lowering the tank by controlled slide down the batter.

11: Ensure that the BiogasPro is rotated so that the risers are perpendicular to the line of the incoming sewer (when viewed from above). The incoming sewer must enter the riser that is labelled IN on the lid, and penetrate through the flat section on the riser. Cut-outs should preferably be made with a hole-saw of the exact and correct size, normally 110 mm.

12: The outlet sewer connection must be done using a T-piece as indicated. During installation, the invert of the sewer outlet is most easily measured from the top of the riser. These invert heights from the top of the riser are 450mm and 720mm for the BiogasPro-6 and BiogasPro-6D respectively. Referring to Figure 4-6), these heights are A + B + C + D + 30 mm.

13: Note that the sewer inlet and outlet, and the gas outlet are duplicated on both sides of the system to provide alternative choices for connections during installation (Figure 4-7).



	A	B	C	D	E	F	Excavation Depth
Biogas Pro-6	0	300	30	90	1775	105	2300
Biogas Pro-6D	270	300	30	90	1775	135	2600

Figure 4-6: BiogasPro installation diagram

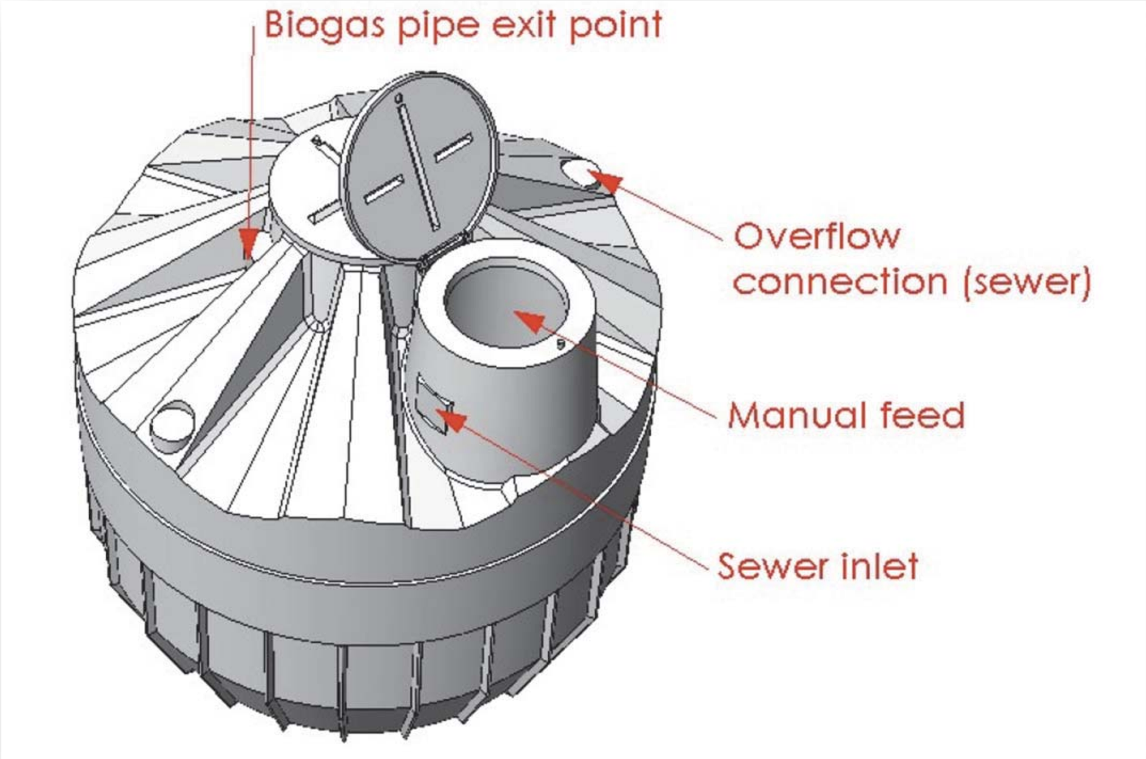


Figure 4-7: Location of main BiogasPro connections

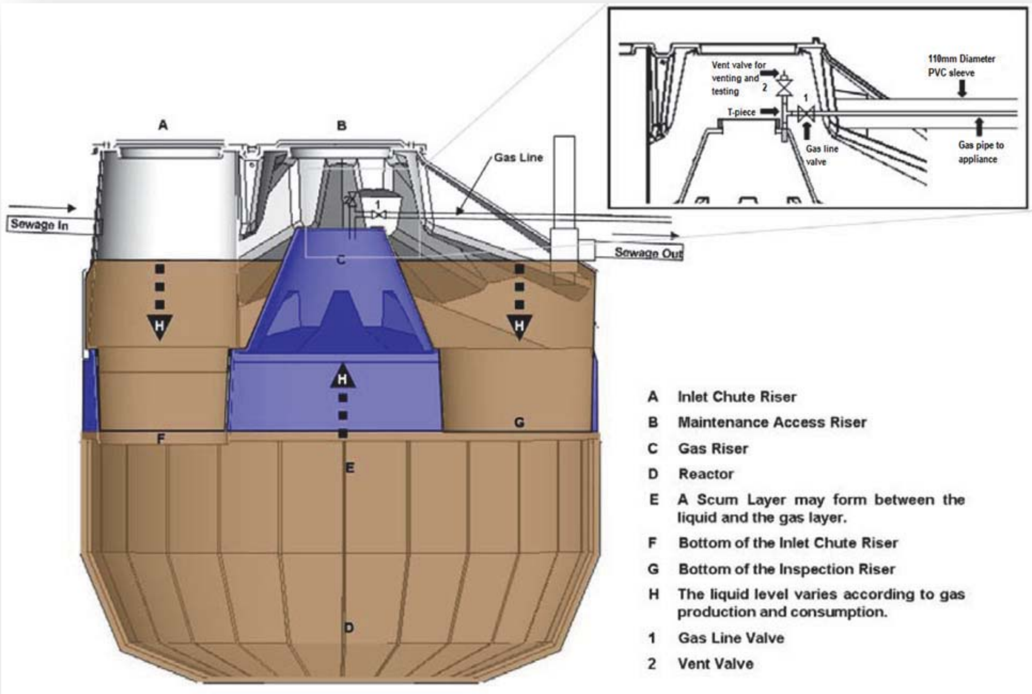


Figure 4-8: Detailed cross-section through the BiogasPro

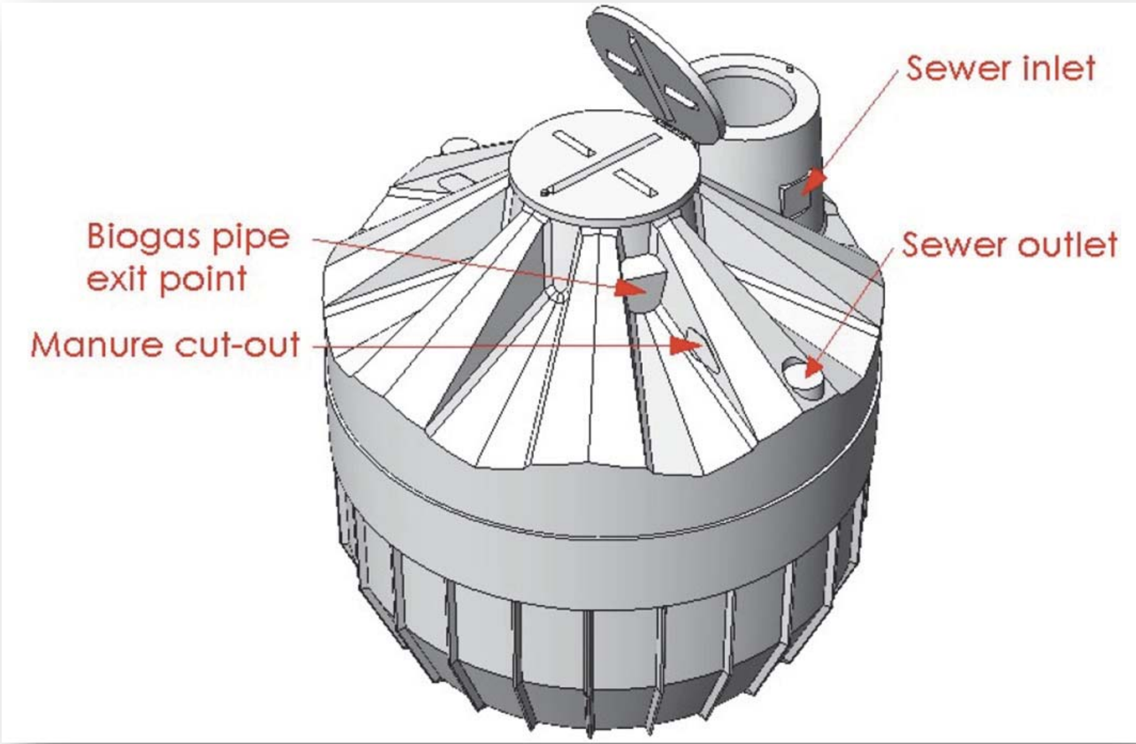


Figure 4-9: Detail showing the manure cut-out locations for the BiogasPro

14: For systems that are going to be fed primarily manure with limited water, a separate outlet from the sewer outlet described above has been provided. This is achieved via a cut-out on the side of the rib adjacent to the biogas pipe exit area, and is also duplicated on both sides of the digester (Figure 4-8).

15: After placing on the sand base, ensure that the BiogasPro is level and plumb by placing a spirit level horizontally across the top of the risers, and vertically up the sides of the tank.

16: Use cement-stabilised soil as backfill, using uniform granular fill such as clean excavated soil or sand (fill must be free of wood masonry debris, silt or clay). Mix 1 part cement to 9 parts clean soil or sand.

17: Ensure that the manhole lids are in place prior to backfilling so that backfill material is not deposited inside the BiogasPro.

18: Backfilling:

a. Ensuring that the vent valve (see Figure 3-15) is closed (or that the gas outlet is plugged), fill the tank approximately 1/3 full with clean water.

b. Backfill and compact to that level in 250mm layers.

c. Continue to fill with tap water and to compact in 250mm layers (always ensuring that the water level is higher than the backfill height).

d. Hand compact and water down and do not machine compact.

e. Do not backfill with large sharp objects that could damage or puncture the BiogasPro.

f. Continue filling the digester with tap water until it overflows via the sewer pipe outlet (or manure outlet).

g. Continue to check for level and plumb through the backfilling procedure.

h. Backfill to the underside of the sewer inlet/outlet pipes, thereby providing support for the underside of these pipes.

i. Fix the sewer pipe inlets and outlets (Figure 4-9). Use the rubber rings provided in the accessory pack to seal the joint between sewer pipe and the digester.

j. Pressure test sewer lines.

k. Finish backfilling to ground level.

l. Open the vent valve (No 2 on Figure 3-15) and release all the trapped air. You will see the water level around the gas riser (indicated as C in Figure 3-15) 'disappear' – it will flow back into the reactor volume.

m. When the air escaping can no longer be heard, close the vent valve.

n. Complete backfilling by creating a moderate slope away from the manhole lids to divert drainage away from the manholes.

19: Ensure that manhole covers are locked on completion of the BiogasPro installation.

20: Where the ground water table is expected to be high, install a reinforced concrete slab over the BiogasPro. This engineered slab design is available from AGAMA Biogas.

4.4.2.1 Health and safety requirements

1: The BiogasPro must be installed according to the Occupational Health and Safety Act No 85 of 1993.

2: Sufficient manpower must be provided to manhandle the BiogasPro.

3: Locations of all underground services should be known so that there is no unearthing of services during excavations.

4: Excavations should be at correct angles or correctly stabilized so there is no risk of collapse.

5: All excavations should have a fall barrier surround to prevent third parties or workers falling into the excavations.

6: Proper ladder access should be provided into excavations.

7: The site should be kept and left clean and level so that there are no trip hazards.

8: All covers must be in place at all times during the installation and covers must be locked on completion of the installation to prevent persons from falling down the risers.

4.4.3 Gas installation guidelines

4.4.3.1 General information

1. The gas installation must be undertaken according to SANS 100087 and SANS 827.
2. The biogas generated by the BiogasPro should be passed through a desulphuriser (supplied in the accessory box) before being used in its otherwise raw state on a purpose-made biogas-burning appliance (supplied by AGAMA Biogas).
3. Raw biogas always contains a certain amount of water vapour that condenses when the gas cools down within the gas pipe. It is therefore imperative to ensure that condensed water does not get trapped within the pipe and block the gas flow. Gas pipes must be laid in a continuous upward slope from the digester to the gas user point and there should be no dips within the pipe that could collect water.

4.4.3.2 Materials handling

1: Pipes, materials and equipment should be checked to see that they have been supplied and delivered as per the manufacturer's specifications.

2: Pipes, materials and equipment should not incur any damage that would cause deformation or weakening, or accelerate corrosion.

4.4.3.3 Supplied gas pipe fittings and gas equipment

1: The digester will arrive with a cardboard box containing the following items (Plate 4-13):

a. Pressure gauge: this must be installed in line above the burner at the user point. The gauge will give the user an indication of the amount of gas within the tank.

b. Desulphuriser: this must be installed inline near to the user point. This mechanism removes corrosive hydrogen sulphide (H2S) from the biogas.

c. Stop valves and T-pieces with venting and testing nozzle: these are to be connected to the gas outlet within the gas riser on the biogas digester.

d. Flammable notice: this is to be installed adjacent to the user point for health and safety reasons.

4.4.3.4 Installation – underground section

1: Excavations should be away from tree roots.

2: General excavation depths should be at least 500mm (the minimum specified depth for gas piping). Pipelines that run under vehicle trafficked areas should be surrounded in concrete or installed at a minimum depth of 800mm and protected with well compacted fill.

3: Excavations should take place shortly before the actual pipe installation to prevent unwanted material falling into the trench.

4: Underground piping should be approved ridged ¾" stainless steel, galvanized steel or steel reinforced HDPE (Ginde) pipes, installed to a maximum length of 70 metres from digester to appliance. Distances greater than this will have a pressure drop greater than 5% of the nominal gas pressure in the digester.

5: When using ridged steel piping the base of the trench should be lined with graded small stone (10mm) on which to bed the pipe. Where HDPE piping is used, a flat concrete foundation levelled to falls should be placed in the trench so that the pipe can lie on an even surface – no dips must be present in the pipe. Inclination should not be less than 1%.

6: Backfill material should be graded sand or stone with no sharp objects that will damage the pipe.

7: Pipe jointing should be as per the manufacturer's recommendations. Joints should be sealed with tape, hemp or grease to prevent leaks as well as corrosion.

8: To prevent restrictions of gas flow the number of pipe fittings and bends should be kept to a minimum. 90 degree bends should be made with 2 x 45 degree bends and within no less than 500mm to avoid sharp changes of direction.

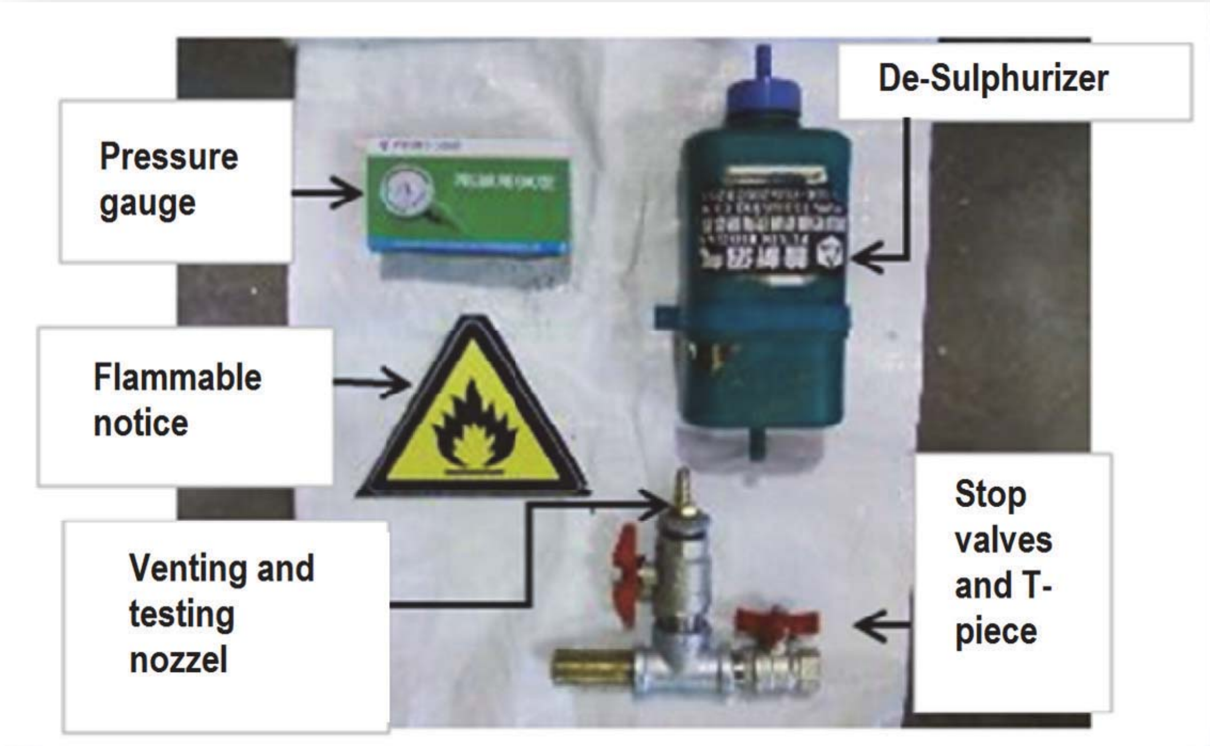


Plate 4-13: Supplied gas fittings and connections (supplied with Agama BiogasPro)

9: 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.

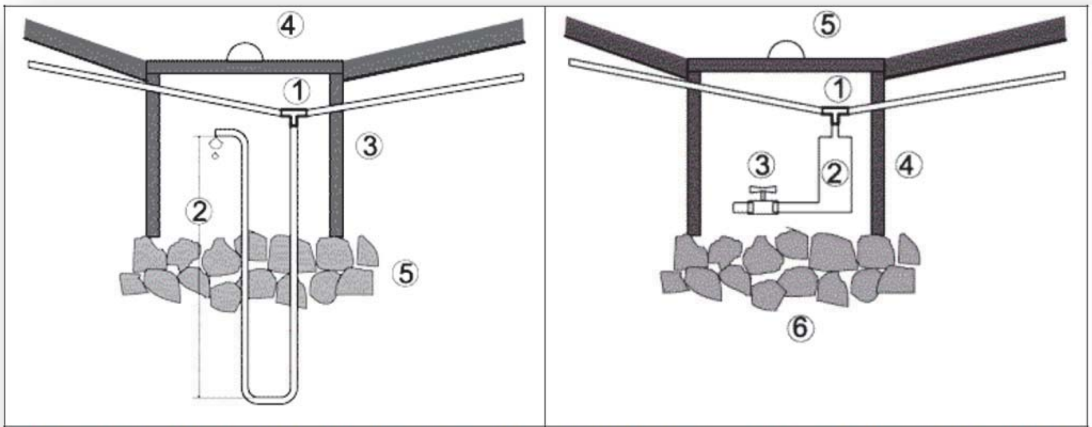
10: Chevron warning tape should be positioned half-way between the top of the pipe and the ground surface when backfilling.

4.4.3.5 Installation – water traps

1: Due to temperature changes, the moisture-saturated biogas will form condensation water in the piping system. Ideally, the piping system should be laid out in a way that allows a free flow of condensation water back into the digester. If depressions in the piping system cannot be avoided, one or several water traps have to be installed at the lowest point of the depression(s).

2: One can install an 'automatic' trap or a manually operated trap. Automatic traps have the advantage that emptying is not necessary. But if they dry up or blow empty, they may cause heavy and extended gas losses. Manual traps are simple and easy to understand, but if they are not emptied regularly, the accumulated condensation water will eventually block the piping system. Both kinds of traps have to be installed in a solid chamber, covered by a lid to prevent an eventual filling up by soil.

3: The diagrams in Figure 4-10 indicated the automatic and manual water trap configurations.



Automatic water trap: (1) T-joint in the piping system at lowest point, (2) water column, **height equal to 100 cm** (max. gas pressure plus 30% security), (3) solid brick or concrete casing, (4) concrete lid, (5) drainage. Note that the water column can be an asymmetric U-trap where the open water pipe ends above ground. The maximum height above the pipe line is half the highest regularly appearing gas pressure (35 cm).	**Manual water trap**: (1) T-joint, (2) buffer storage for condensed water, (3) manual tap, (4) casing, (5) concrete lid, (6) drainage

Figure 4-10: Water trap options for the biogas line

4.4.3.6 Installation – underground to gas user-point

1: ½” copper or HDPE pipe should be used from the main distribution pipe (underground pipe) to the proximity of the burner at the user point.

2: The ½” piping must be securely fixed to the wall inside and outside at the user point.

3: An approved flexible hose pipe should be connected between the ½” pipe and the burner (the flexible pipe must be less than 1.5m).

4.4.3.7 Installation – gas piping configuration within and exiting the digester

1: The BiogasPro will be supplied with two steel stop valves (a vent valve and a gas line valve), a T-piece, a venting/testing nozzle, and threaded nipples (Figure 4-11).

2: These should be assembled and fixed to the tank’s gas outlet, which is a threaded female component on the top of the gas riser. Components should be assembled using thread tape to achieve gas tight seals (Figure 4-11).

3: Do not remove or loosen the removable gas cap.

4: From the outside of the digester drill a 110mm hole through the biogas pipe exit point (Figure 4-12).

5: Fit a 500mm long 110mm PVC sleeve, protruding through the gas maintenance access riser wall (the sleeve is positioned to allow flexibility for movement of the gas pipe caused by changing internal gas pressure) (Figure 4-13).

6: Fit the external gas pipe and connect to the internal gas pipe configuration.

7: Apply an anti-corrosive cover (painted coating, bituminous tape or similar approved) to all steel components on the piping configuration.

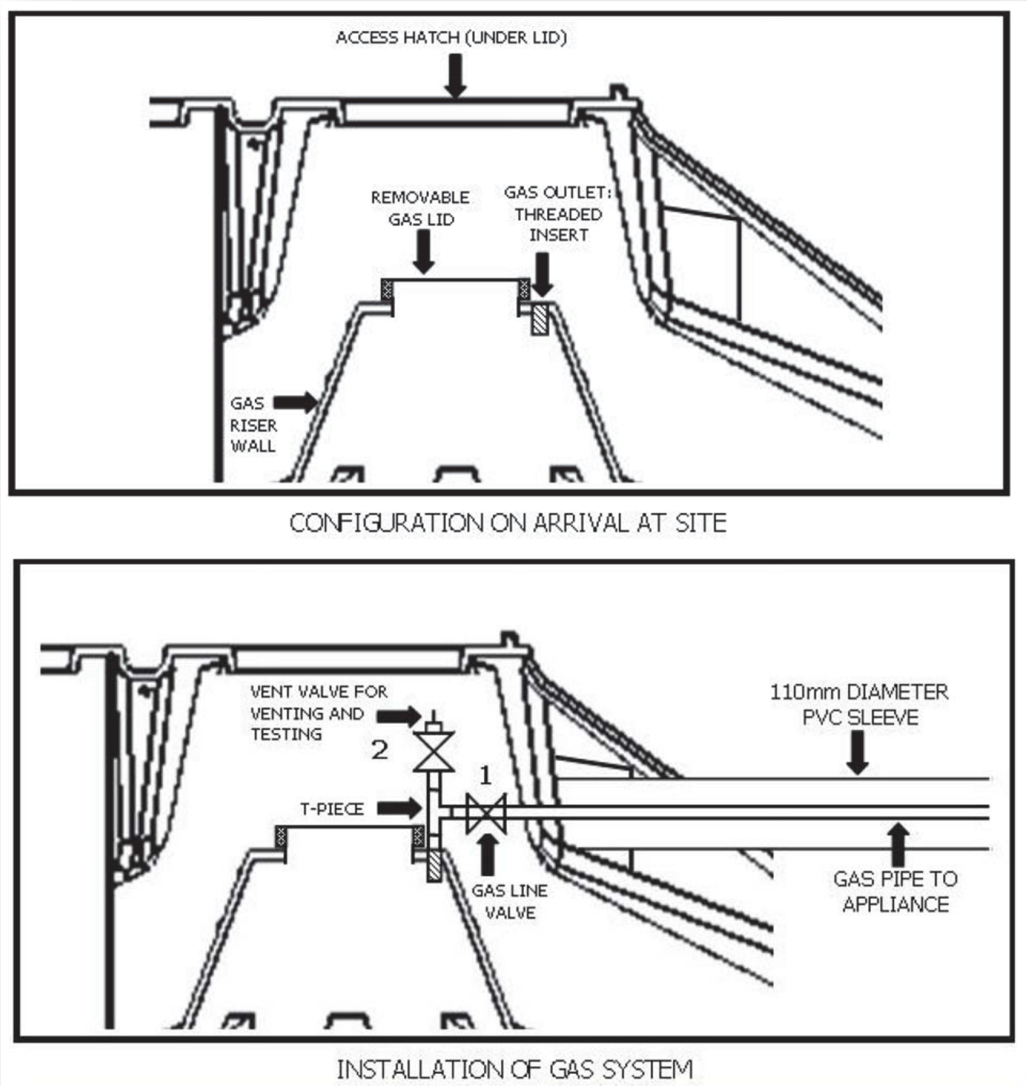


Figure 4-11: Gas outlet configuration within and exiting the BiogasPro

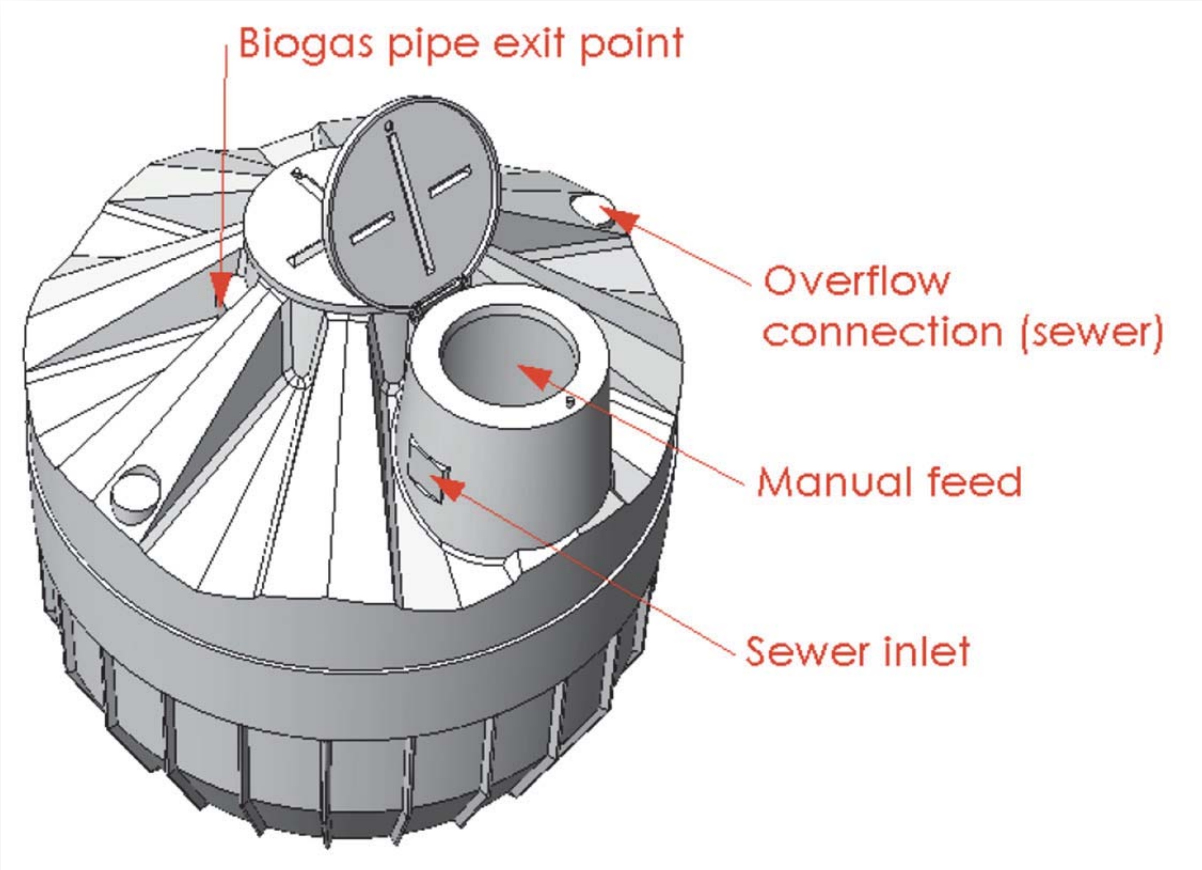


Figure 4-12: BiogasPro primary connection points

4.4.3.8 Installation – to completion

1: Pressure test the gas system. The gas can only be tested to a maximum of 6.75 kPa and only when the BiogasPro has been filled with water to the over flow point. 6.75 kPa is achieved by pumping air through the vent valve (with the gas line valve closed). In achieving 6.75 kPa pressure, approximately 0.95 m^3 of water (= the gas storage volume) within the reactor chamber is displaced. Air bubbles will be observed rising up from the Expansion Chamber by looking through the Gas Riser down to the water surrounding the Gas Compartment, once 6.75 kPa has been reached.

2: Pressure test the gas line and the rest of the installation.

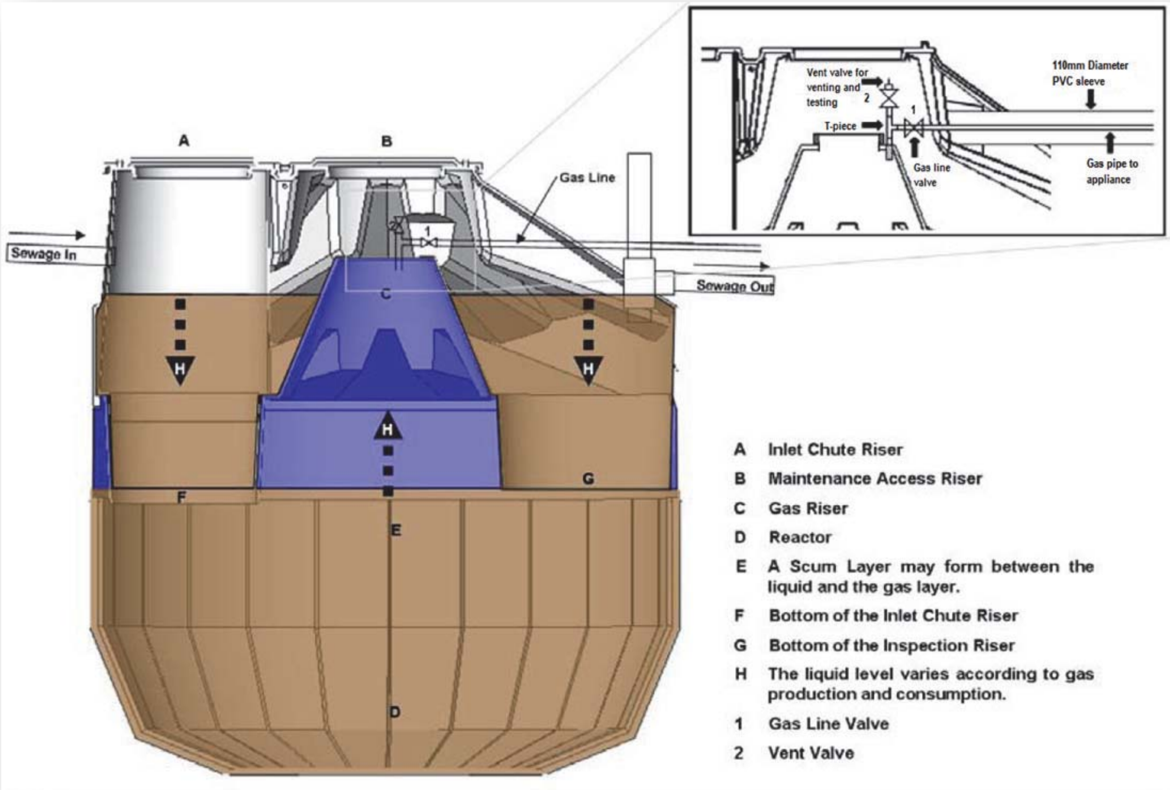


Figure 4-13: Detailed cross-section through the BiogasPro

4.4.3.9 Connecting to the gas burner

1: The burner 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.

2: When siting the burner, due regard should be paid to the convenience of use, protection from draughts and damage and to the layout of the piping system.

3: Flexible pipe runs should be as neat and as short as possible (but not longer than 1.5m). There should be no undue strain on the pipe work and it should be kept well below the level of the open burner.

4: The flexible gas feed pipe should only supply one burner i.e. there should be no T-junctions to another appliance along its length.

5: Hose clamps must be used on flexible pipe connections.

6: Shut off valves should be easily accessible.

7: Appliances shall not be installed in small confined spaces that are poorly ventilated, as the burner requires an unrestricted supply of fresh air.

8: Burners must be situated so that there is no danger that they could set fire to furnishings (e.g. under a shelf or adjacent to curtains).

4.4.3.10 Health and Safety

1: The gas installation must be undertaken according to the Occupational Health and Safety Act No 85 of 1993

2: Use manufacturer specified materials and equipment (piping, fittings, valves, clamps, etc.) only.

3: Ensure underground pipes are installed to the specified depths.

4: Ensure correct positioning of shut-off valves as well as free and full movement of the valves.

5: Ensure that appropriate "biogas system, flammable gas" signage is posted at the digester and the user point.

6: Ensure sub-surface pipe work is correctly supported.

7: Ensure suspended pipe work is correctly supported.

8: Ensure correct jointing of sub-surface and suspended pipe work.

9: Ensure all newly installed pipe work is not damaged or corroded.

10: Ensure that flexible tubing connected to the burner is below the flame.

11: Ensure that the burner is not positioned near combustible material (e.g. under flammable shelving or close to curtains).

12: Locate wall-mounted gas piping at least 200mm away, and electric cabling 1m away from the burner. Nearby electric cable must be firmly supported with purpose-made clips or hangers.

13: Ensure that the burner is well supported.

14: Ensure that the burner is located in a well-ventilated location.

15: Ensure that the burner is not located in a draughty area where the flame could be blown out or blown onto combustible material.

16: Educate the user about the installation in general as well as the fact that a dry powder extinguisher should be in a clear and visible location near the appliance.

4.5 OPERATING A BIOGASPRO DIGESTER

Although the BiogasPro is convenient and easy to operate, the user needs to understand the basic theory behind the system operation. This is a biological system that responds best to a consistent operational and loading regime. It should also be understood that a biodigester is a dynamic, living system, and the user should change feeding behaviour based on observed changes in the system (e.g. the consistency in the slurry). If possible, the installing service provider should be consulted from time to time to ensure that the system is working effectively.

4.5.1 Loading the BiogasPro digester

1: Load the system with no more than its designed loading capacity (Table 4-11). This will ensure optimal gas production and complete breakdown of feedstock preventing post-digester effluent treatment systems being overloaded (i.e. in an urban septic tank setup). It will also ensure a long uncomplicated operational life span of the system.

2: The table below indicates the maximum amount of any one feedstock that can be added daily, noting the following:

- Mix a combination of the prescribed maximum loading limits to make up the daily load. For example, you should mix no more than half the maximum food waste (= 17.5kg) with half the maximum cow manure (= 25 kg) daily.

- Chicken layer manure should always be mixed with another feedstock and never be fed to the digester in isolation (this is due to the high nitrogen content of chicken manure, which increases tank acidity and reduces performance)

Table 4-11: Daily maximum loading limit of the BiogasPro

Feedstock	Daily loading limit
Cow manure	50kg
Food waste	35kg
Grass silage	25kg

3: The optimal ratio of fresh feedstock to water is 1:1 (i.e.1 kg of feedstock to 1 litre of water) when the feedstock is fresh (NB. see Case study 4.4). If the feedstock is dry, then this ratio must increase (add more water). However, not more than 1 000 litres of water must be added daily. For example you can load 50 kg of cow manure together with up to 1 000 litres of water, but the performance will be better (more gas will be produced) if you reduce the amount of water to nearer 50 litres (1:1).

4: Manure should be mixed thoroughly with water to create a consistent slurry (Plate 4-14 and Plate 4-15). Mixing helps to make all particles of the manure accessible to the bacteria. Dry pieces of dung (that will often float) are not accessible to the bacteria and will block the system.

Plate 4-14: Fresh manure (20kg) is separated into two buckets (left), 20 litres of water is shared between these buckets (right)

Plate 4-15: The manure-water mixture is mixed by hand or using an implement (left), and then poured into the digester once thoroughly mixed (right)

Plate 4-16: The inlet can be mixed with a stick, after feeding or on alternating days

5: It is preferable to periodically mix the feedstock in the inlet riser to avoid clogging up (Plate 4-16)

6: All organic, non-lignin biodegradable material (feedstock) can be fed as long as it is not too fibrous and preferably well chopped (< 2.5 cm). Anything that a stomach will digest can go into the digester (4.2.1.2).

7: Performance is better with a more diverse range of feedstock, for example, mix manure with kitchen scraps.

8: Ideally the same/similar mix of feedstock should be loaded every day. Changing the feedstock abruptly can cause the BiogasPro to go into 'shock' – causing performance and gas production to drop.

9: The more feedstock you load into the BiogasPro, the more gas energy and nutrient material it produces. This is only true, however, when temperature allows the digestion process to continue. Limits on the loading amounts are outlined above and should NOT be exceeded.

Note: A biodigester should be treated like a living animal. The operator should pay attention to its changing characteristics on a daily basis. If the slurry appears to be partially undigested, it may be necessary to decrease the organic loading rate. If the slurry appears to be too thick (i.e. thicker than a runny soup) then a higher ratio of water should be added. One can even re-feed some of the exiting slurry into the digester, if it is clear that the digestion process is slow – this can help by increasing the bacterial concentration in the system, and allowing more time for the bacteria to eat the solids.

4.6 EDUCATION AND TRAINING PROGRAMME

A biodigester is not a 'plug and play' technology, but rather a system that must be tended to on a daily basis. The consistency of feeding, use and maintenance is directly proportional to the outputs and benefit of the system. As an investment, it is important that the financial and economic returns are realised, and this can only be achieved by ensuring that the system works well and is well used by the owners.

4.6.1 Initial training of users

First round training of new biodigester users is a critical necessity and has proved to be necessary in rural and urban, educated and uneducated environments alike.

Education

Users should first be educated about the basic concept of anaerobic digestion and how a biodigester works. This education should be designed for the receiving audience, and topical analogies should be used where possible. In the KZN rural context, it became evident that the fermentation of compost, and the heat that was generated in this process, was a suitable example of the description of the natural and self-perpetuating reaction that takes place in a biodigester. It is important that these explanations be made by someone who can not only speak the appropriate language, but has a sound understanding of the culture and its niceties to deliver the message clearly (Plate 4-17).

While it is inconceivable to educate users on the intricacies and details of all chemical reactions that take place in a digester, it is important that they understand the nature of this 'living system' and can then be directed to care for it appropriately.

It is advised that the following topics be covered in this initial education process:

- The natural process within a biodigester (keep it simple).
- What anaerobic bacteria can and cannot digest (or eat).
- The importance of feeding/operational consistency for the bacteria within a digester.
- A basic explanation of how the system is susceptible to varying conditions (e.g. temperature changes).
- What is biogas and bioslurry.
- How safe is biogas and how should it be treated.

Plate 4-17: David Alcock fluently explaining the process of anaerobic digestion at a WRC K5/1955 pilot household in KZN

Training

Once a baseline education has been given, the households should be trained on the correct operation of a digester. This process has been outlined in Section 3.7 and should include:

- Feeding methods and regime.
- How to use biogas, and efficient cooking methods.
- General inspection for maintenance.

Although a biodigester can produce enough biogas for the daily cooking requirements of a four to five people household under optimal conditions, the system does not always run optimally and the WRC project K5/1955 has identified preliminary findings that suggest gas production is insufficient under various circumstances (e.g. cold winter months)[3]. It is, however, possible to use efficient cooking methods which can significantly extend the abilities of biogas to cook a meal. Efficient cooking methods can include the use of a 'Wonderbag' (a thermal insulating bag in which a hot pot can be placed), pressure cookers, or simply well planned time management in the kitchen (Plate 4-18). The training process should include an interactive display of the use of these efficiency methods and should be followed up in later training programmes (Plate 4-19).

Plate 4-18: Dr Monique Salomon showing how a Wonderbag, or home made alternative, can be used for efficient cooking (left), Dr Terry Everson showing the use of a pressure cooker on a blue biogas flame (right)

[3] This is a preliminary finding which is not confirmed by scientific evidence. The WRC K5/1955 team continues to explore this research through remote monitoring and empirical evidence (see Case study XX).

Plate 4-19: A meal cooked on biogas during an efficient cooking method training session (left), the meal was cooked on biogas for 14 people including WRC K5/1955 team members and biodigester users (right)

4.6.2 *Recommended training programme*

It is highly recommended that the initial training of households be followed up with subsequent monitoring / training visits. It became apparent in the course of the WRC project K5/1955 that biodigester users could easily develop misconceptions about the system, leading to suboptimal operation. Some of these misconceived notions included:

- Households thought they could 'save gas' for days when they most needed it.
  - The BiogasPro system has a gas storage capacity of ~1000 litres and under optimal conditions more than 1000 litres is typically produced in a day.
  - When the tank is full, gas is vented into the atmosphere (a negative environmental impact as methane is a strong greenhouse gas [GHG]).
  - Daily use actually promotes stirring in the tank and biogas production.
- Despite the fact that this had initially been outlined, households needed to be persuaded that the bioslurry was a valuable nutrient fertiliser which could be used on their crops.
- Biogas was being used inefficiently and the benefit was therefore not fully realised.
  - The team recognised the need for efficient cooking tools and methods, and therefore provided the equipment and training (Plate 4-18).

The training schedule to be implemented can be dynamic to changing circumstances and the abilities of the users. Training should, however, not be compromised – as it is a critical component of biodigester use and subsequent realisation of output benefits. An inappropriately managed or used biodigester is not only a useless entity, but a detriment to the delivery of services via renewable energy and potentially damaging to the way in which alternative options may be perceived. It is, therefore, critical that the training component of a biodigester (or other renewable energy) project be carefully planned and budgeted for.

Figure 4-14 displays a proposed training/monitoring schedule for a biodigester installed at a rural home. As noted, this is open for change in varying settings, but should include a strong initial engagement and follow-up programme. Empirical evidence from WRC project K5/1955 suggests that the following schedule would be appropriate and beneficial in a rural setting in South Africa:

- Initial engagement.
- Follow-up site visit and refresher training (as appears necessary) when the biodigester starts producing gas at approximately month one end.
- Follow-up site visit and refresher training not less than one month following previous visit – to strongly deliver the message of correct operation and use.
- Site visit to monitor digester health and refresh household on all management and use activities at approximately month six, and month 12.
- Bi-annual site visit in year two, if deemed necessary, and an annual digester check-up in subsequent years.
    - The necessitation of these visits relates more directly to the maintenance of the biodigester systems, and it is hoped that a suitable maintenance programme can be established to release project developers/trainers from the onus thereof.

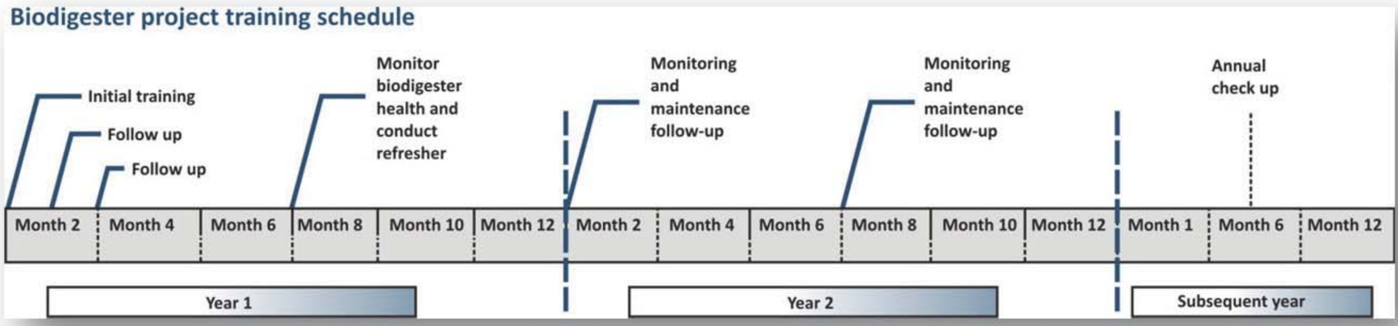


Figure 4-14: A proposed timeline of a training schedule for biodigester using households in a rural context

4.7 TECHNICAL SUPPORT AND MAINTENANCE

It has been the experience of the WRC project K5/1955 team that although a well installed and operated biodigester is unlikely to have major failures, it is important for technical advisors to be on hand for technical difficulties that come about from operation in a real world, developing country scenario where people have had little experience with the operation and use of biodigesters.

4.7.1 Support and maintenance requirements

The social, economic, and environmental benefits (of which there are many) of a biodigester can only be realised if it is effectively operational. For this reason, a project which aims to deliver social upliftment through the installation of biodigesters, can only do so if they are operational into the future. It is, therefore, imperative that a biodigester programme comes hand-in-hand with a support and maintenance programme that ensures their continued operation.

Likely faults of a biodigester system include:

- Blockages in gas lines (see Case study 4.2).
- Blockages in digester tank as a result of overfeeding or feeding of inappropriate materials (see Case study 4.5).
- Unexpected damage to the digester, gas line, or utilisation equipment (see Case study 4.8 as an example).
- Replacement of biogas burners or utilisation equipment.

The above listed maintenance items are those which are most likely to be experienced by a biodigester user and therefore technical support staff should have the equipment and skills to (i) identify these type of problems, (ii) fix them or action their repair.

Case study 4.8 presents an interesting and relevant example of a fault that a household would be unlikely to identify or fix, but that a technical support assistance should be able to assist with. In this case, the household was unaware that they had damaged a subsurface gas line, and the system therefore had no useable biogas. Although simple protocol was required to identify this fault, the troubleshooting skills are not those which would be easily imparted on a rural household user.

4.7.2 Support and maintenance programmes

The running of a support and maintenance programme requires significant resources, whether a few or a few hundred biodigesters have been installed. Inexperience with scaled-up scenarios in WRC project K5/1955 means that a suggested programme of action for this task would be unqualified. From experienced in the project, however, it appears possible that a skilled and equipped technician would likely be able to visit two digesters per day, if they were in the same area. This would mean that an equipped and mobile technician could potentially visit and address any problems at 50 biodigester sites, in proximity to a specific community or area, in a given month.

The question applicable to this discussion is, "Who should be responsible for the funding of a support and maintenance programme?", and the following two scenarios are *NOT* suggestion but are raised to stimulate discussion on this topic:

1. The local government should support and maintain the biodigesters in an area?
   - This proposition is built on the notion that a local government is typically responsible for the support and maintenance of service provision, including electricity and water supply. The delivery of services from a biodigester, albeit off-grid, is still a service which could be provided by the government as an alternative to grid provided services. If this were the

case, it follows that the provider of this 'service' would be responsible for its maintenance, and the ability of the system to continue providing a service.

2. The biodigester using households should pay a monthly fee for the maintenance and support of their biodigester?

    - If a project were to be funded by a non-governmental organisation, or even if households were to purchase their biodigesters in their private capacity, it would appear sensible that some form of funded maintenance programme be initiated and sustained. In this scenario, it would seem appropriate that, like any service, a household be responsible for some payment of that service. The suggestion herein is quite simply that the household should be paying for a 'service contract', to ensure that their installation continues to be operational into the future. Orchestrating a system of this nature, the actual transferal of funds, and educating a population about its relevance or need, is likely to pose many challenges – gas from a biodigester system cannot simply be shut off, when a household refuses to pay a maintenance bill.

4.8 CASE STUDIES: LESSONS AND LEARNING FROM WRC PROJECT K5/1955

This section of the report presents a number of empirical case studies from the WRC project K5/1955. While the theoretical application of biodigester systems for rural areas is valuable, case studies of actual experiences with biodigester installations can teach us a lot about their actual application in 'real world' scenarios.

Case studies from WRC K5/1955

Case study 4.1: Agama BiogasPro6 versus Sintex digester

Agama BiogasPro 6: The Agama BiogasPro 6 is a 6 000 litre pre-fabricated tank digester, designed and made in South Africa.

Sintex: The Sintex is a 3 000litre pre-fabricated tank digester, made in India

Findings: Comparison of the two digesters (Plate 4-20), installed in close proximity in the Eastern Cape village of Machubeni and4 fed with a similar 1:1 mixture of cow dung:water, revealed that the BiogasPro 6 performed substantially better than the Sintex.

It must be noted, however, that the Sintex is a substantially smaller digester. Production rates per kilogram of l4oaded material were closer (although the BiogasPro still significantly outperformed the Sintex (Figure 4-15).

Considering an average households needs, it is recommended that the BiogasPro is a more suitable pre-fabricated tank digester for South African conditions.

Plate 4-20: Agama BiogasPro (left) and Sintex (right) pre-fabricated tank digesters

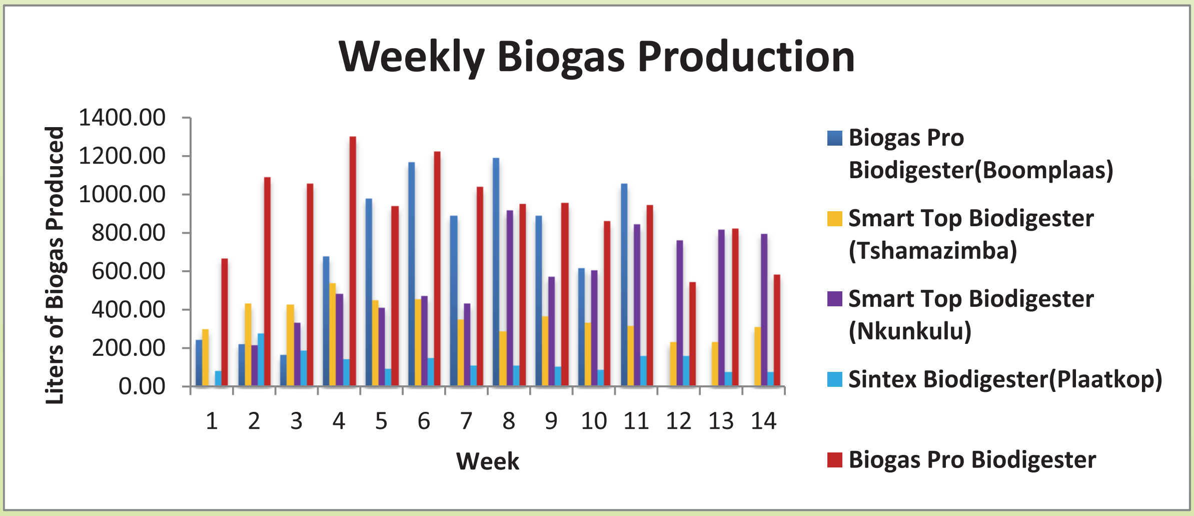


Figure 4-15: Weekly biogas production of various types of biodigesters at the WRC K5/1955 Eastern Cape pilot study sites

Case study 4.2: Moisture and blockages in the gas line

Problem: The problem at the Potshini pilot household (KZN) became evident when pressure at the gas burner became very low, with intermittent 'spluttering' and after sometime entirely ceased gas flow.

Action: The research team attempted first to unblock what was thought to simply be moisture by using a compressor to blow out the blockage. This would work with a moisture block and/or minor solids block, but in this case it was necessary to remove valves and the gas line, clearing the valves manually and blowing the gas line with pressurised air (Plate 4-21).

Cause: It is believed that the problem was a result of the household not emptying the slurry pit, and then using the gas – allowing moisture and slurry to force its way into the gas line.

Solution: Slurry pits should be fitted with spill-over / fail-safe overflow mechanisms that do not allow digestate to back-up into the system. Households should be vigilant that the slurry pits are emptied and not blocking the digester. It is also advised that a moisture trap be installed at households and/or gas lines be directed at a negative slope back into the digester.

Plate 4-21: Clockwise from top left: overflowing slurry pit, blocked gas line, blocked gas valve, moisture trap

Case study 4.3: Avoiding problems related to slurry outlet blockages

Problem: If the slurry outlet is not correctly placed so that the slurry freely and continuously exits the digester, digestate backs up into the system causing a number of problems, including blockages.

Solution: If there is a slope available to the installer, the slurry exit should be placed at a point lower than the digester with an overflow mechanism that allows for excess digestate to safely flow away from the digester (Plate 4-22).

It is often the case that no slope is available, and therefore the digester should be built slightly higher in the ground and/or a downward sloped slurry outlet should be directed into a collection pit with sufficient storage capacity to (i) meet the needs of the users, (ii) be big enough to reduce the chance of filling up and backing into the system.

Plate 4-22: Clockwise from top left: digester installed on slope, digester installed at location with no slope, large slurry collection pit, slurry outlet installed on a slope below the digester

Case study 4.4: Overfeeding of a digester with organic matter

Problem: The problem at the Okhombe household (KZN) became evident when gas production and pressure were significantly decreased, and the inlet and gas chambers filled to capacity with digestate.

Action: The problem at the Okhombe digester was a serious one, requiring professional assistance. A slurry pump was used to mix and empty the digester, so that the digestion process could be started again (Plate 4-23).

Cause: It is expected that the cause of this problem was the result of overfeeding the digester with organic matter, coupled with a slowed down digestion rate over the cold winter months.

Solution: Further research needs to be conducted to understand the impacts of temperature on digestion rates. It is possible that a varied rate of water to organic matter will be required at different times during the year as temperatures change. Education and training are critical in promoting sensible self-moderated changes in feeding practice, to meet changing circumstances and digester operation.

Remote monitoring devices (see Case study 4.12) have been installed to better understand all impacts.

It is noted: that the problem described here turned out to be partially or fully a result of a cracked digester (see Case study 4.11). It is included, none-the-less, as the experience is what would be expected in the case of an overloaded digester. Overloading is still expected to have been part of the problem at this site.

Plate 4-23: Clockwise from top left: blocked inlet chamber at capacity, slurry-pump filter blocked by solid matter, mixing the digester with a stick and slurry pump, emptying the digester

Case study 4.5: Reduced gas capacity due to lignin blockages

Problem: Households reported insufficient gas, despite high gas pressure readings on their gauges indicating full gas chambers.

Action: Gas chambers were inspected. A fine ligneous material was discovered (Plate 4-24). The material was incredibly fibrous and porous with low moisture content. It did not have the strong smell of either the raw feedstock (manure or the bio-slurry). It was removed and the gas chambers resealed.

Cause: Inadequate mixing of feedstock (cow manure and water), over-feeding the digesters, and feeding of indigestible (dry or ligneous material). This was compounded by the low digestion rate during the cold winter months.

Solution: Dry manure and lignin rich material should not be used as feedstock. Additionally feedstock should be mixed thoroughly. Mixing the feedstock in a separate container and allowing it time to settle could assist. The Nkiti household at Tschamazimba that pre-mixed the feedstock did not experience any problems with blockages of the gas chamber.

Plate 4-24: Clockwise from top left: (a) High gas pressure, minimal gas, (b) opened gas chamber, (c) solid mass of ligneous material, and (d) light fluffy consistency of the ligneous material

Case study 4.6: Extreme weather conditions

Problem: High rainfall events made transportation and installation of biodigesters troublesome. Additionally, low temperatures during winter reduce the biogas potential of biodigesters, which perform better at higher temperatures.

Solution: Careful planning must be done to ensure installation is conducted during summer, to take advantage of drier conditions and higher temperatures (area dependent). This is especially useful for a quicker commissioning of the biodigesters, allowing microbes to reach critical mass faster. Biodigesters are buried in order to insulate and regulate internal temperatures. Additionally, mixed feedstock can be allowed to stand in the sun for the duration of the day, to allow for minimum heat loss through the addition of cold water.

Plate 4-25: Clockwise from top left: (a) Typical road conditions after a major rainfall event. (b) Numerous rivers in the area flood on a regular basis c) Overnight temperatures plummet below zero, and (d) Burying the biodigester assists with insulation.

Case study 4.7: Irregular loading and overloading of digester

Problem: Biodigesters have minimal gas production and produce a thick bioslurry.

Action: The daily feeding regime of each household was monitored over a 14 week period.

Cause: Whilst feedstock was abundant, the labour to collect it and mix it was not always available to these households, particularly over weekends, holidays and events (funerals). Households compensated for this by doubling up on feedstock for missed days (Plate 4-26). Additionally, the feedstock to water ratio needs to be further investigated.

Solution: Further study into the best feedstock loading ratios needs to be conducted, taking into account temperature variations between summer and winter.

Plate 4-26: Clockwise from top left: (a) Cattle dung serves as the primary feedstock, (b) Additional mixing of feedstock within the biodigester, (c) Consistency of the feedstock is very thick and additional water is added and (d) evidence of overloading the digester as material accumulates above gas inspection hatch.

Case study 4.8: 'Unexplainable' loss of gas/gas pressure – identified as punctured gas line

Problem: A remotely monitored (see Case study 4.12) digester suddenly lost gas pressure and the household reported no useable gas.

Action: The WRC K5/1955 team visited the site and identified that there was no gas available for cooking, despite the fact that the digester appeared healthy and was clearly producing gas. The team began troubleshooting the problem. A gas line fault or punctured digester tank were hypothesised so the team:

- Inspected the visible part of the tank – no leaks were obvious.
- Closed the gas line valve, waited 15 minutes before opening the gas test valve. The tank had filled with gas and pressure was available (i.e. the tank itself had no leaks and the problem was likely to be along the gas line).
- Questioning the household revealed that a new fence had been erected around the digester, and the team noticed that a fence pole had been plunged into the ground in proximity to the gas line.
- Excavation at this point revealed that the fence post had cut through the gas line (Plate 4-27).

The gas line was repaired, and immediately gas became available at the gas burner.

Cause: A new fence had been erected and a fence post had punctured the gas line.

Solution: The household should be notified of the location of the gas line, and/or the line should be protected, and/or the line location should be marked.


Plate 4-27: Fence post hammered into the ground (left), gas line cut caused by fence post (right)

Case study 4.9: Cracked and leaking gas chamber

Problem: A BiogasPro at an Okhombe pilot site stopped providing gas to the household.

Action: The WRC K5/1955 team inspected the tank and gas line as per Case study 4.8. No obvious problems could be identified. The team therefore troubleshooted the problem further:

- The gas line valve was shut off and bubbles began to appear as gas built up.
- Air was pumped into the tank using an air-compressor and two distinct problem areas were identified.
- Digestate was extracted from the tank, two major cracks were revealed (Plate 4-28).

Cause: No direct cause could be identified, it is however believed that the tank design was resulting in a thin (weak) layer of LDPE plastic in the problem areas (this has been fixed), and that top loading of soil on the digester – as well as an unsupported base – resulted in lateral pressure cracking the tank at these weak points.

Solution: LDPE patches proved unsuccessful and the tank had to be replaced (see Case study 4.11). The tank design has been strengthened. It is also advised that the tank be carefully installed so that pressure is evenly distributed across the base of the tank (see Case study 4.11).

Plate 4-28: Tank pressurised to identify fault areas (top), cracks revealed after digestate was removed to drop water/digestate level (bottom).

Case study 4.10: Flooding of sub-surface slurry pits and digesters

Problem: Sub-surface slurry pit and/or biodigester flooded with water during heavy rains. If a slurry pit is being flooded (Plate 4-29), this can often result in back flow of water into the digester.

Solution:

- Pre-installation: the slurry pit and the digester tank should not be built in such a way that they are below the surrounding land and therefore prone to being flooded. If this is unavoidable, drainage systems must be installed to direct water away.
- Post-installation: if the digester or slurry pit is flooded, remedial work must be actioned to divert water away from these access points. If drainage cannot solve the problem, the rim around the pit and the digester must be built up and above the 'flood line'.

Plate 4-29: Clockwise from top left: A digester installed below ground level and prone to flooding; a digester installed slightly out of ground to avoid flooding; a flooded slurry collection tank; two slurry collection pits that will likely be flooded

Case study 4.11: Biodigester tank extraction and replacement installation process

The following images (Plate 4-30 - Plate 4-35) present a graphical display of the process of removing a digester and installing a new one in its place. Emptying the existing digester is a challenging process, as digestate must be stirred and mixed with water repeatedly before it can be extracted by a pump).

Plate 4-30: The old tank must first be emptied (left), poles are used to help slide the tank out as it is pulled with a chain

Plate 4-31: The hole is prepared with a sand base and using an automated or manual stamper (left), cement and sand is used in various ratios to stabilise the soil as required (right)

Plate 4-32: The new tank is carefully lowered into the hole (left), a spirit level is used to ensure that the tank is level on installation

Case study 4.12 continued…


Plate 4-33: The soil around the tank is mixed with cement for stabilisation, this can be done to varying degrees as required per site (left), the tank must be filled with water as sand is compacted around the tank – this is necessary to avoid the tank collapsing inward from external pressure (right)


Plate 4-34: A remote monitoring station (see Case study 4.12) is installed at this site (left), the surrounding ground is lightly compacted as the tank is filled with water

Installing a new tank requires that the tank be filled with water as soil is placed around the tank. Water is also required to initiate the biodigestion process and ensure that the slurry can flow fluidly in the beginning phases. When this digester was installed at the end of dry winter months, no immediately local water was available – this posed enormous challenges for the team, and access to 4 500 litres (per installation) of water must be considered by project developers.


Plate 4-35: Collecting water from a river some distance away from the installation site (left), after a number of trips, the trailer broke under the load of water transportation along bad roads (right)

Case study 4.13: Renen Energy Solutions BiogasProMeter, remote monitoring system

Description: A BiogasProMeter is a system developed by Renen Energy Solutions (Pty) Ltd to monitor internal and external environmental variables of a biogas system (Plate 4-36). The custom made systems for WRC K5/1955 are capable of monitoring:

- Changes in gas pressure
- Gas usage (based on gas pressure and an algorithm to determine quantity usage)
- Biogas loss (i.e. vented gas) – calculated via an estimation model based on gas production cycles
- Tank temperature
- Air temperature

In addition, the system can be adapted to include other monitoring (e.g. tank lid opening and/or early warning messages to notify the team of potential problems).

Why remote monitoring:

The WRC K5/1955 team identified that standard gas usage metering was limited in many respects, and could not define how much gas was being produced (i.e. only how much was being used), at what time it was being used and for how long it would last. These usage/production patterns and changes could also not be compared to air and tank temperatures, and the team wanted to better understand the effects of temperature on gas production. The team continues to monitor all these variables.

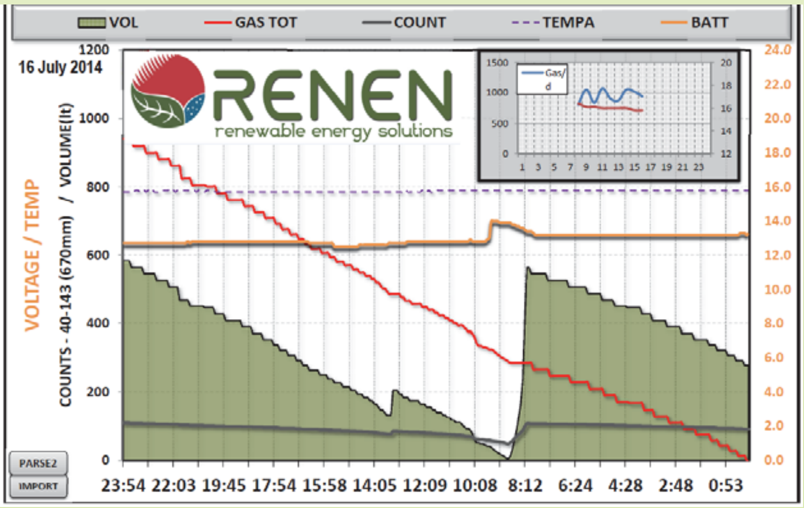


Plate 4-36: BiogasProMeter developed and installed by Renen Energy Solutions at Okhombe pilot household (left), an example of the BiogasProMeter data available remotely from the monitoring system (right)

4.9 BIOGAS FOR RURAL AREAS: RECOMMENDATIONS

Based on the practical experiences and research undertaken through WRC project K5/1955, the following key recommendations are highlighted from this guidelines report:

- Basics of anaerobic digestion
  - Biogas is most easily used as a cooking fuel in a rural setting.
    - Interestingly, pilot households have also reported that biogas was preferable to other cooking energies (including electricity, which they said to be prone to numerous outrageous).
  - Bioslurry is a nutrient rich fertiliser which can be used for food and fodder crop production.
  - There are many different types of biodigesters and the needs of the receiving household/user should be considered carefully before choosing one. A pre-fabricated tank digester appears to be one of the most suitable designs for the South African rural setting – due mainly to its ease of installation and reliability as a factory tested unit.
- Community engagement
  - Local authorities, tribal authorities and a community itself must be approached respectfully for the support of a biodigester project.
  - The support of these parties, and especially the people within a community, is crucial to the success of a project. Community engagement must be carefully planned and undertaken.
- Household selection
  - It is often necessary that households must be selected for a biodigester project.
  - Depending on the type, scale and plan of the project, household selection must be enacted carefully and with inclusion of the local community leadership.
  - Suitability of a household for biodigester operation and use is a pre-requisite.
  - Including the community in the selection process, and keeping them informed, will assist greatly in gaining their acceptance of the process and their support of the project.
- Biodigester installation
  - Biodigesters need to be installed carefully and within the recommendations of the suppliers and/or professional artisans. A failing biodigester is often difficult to remedy and detrimental to the conceptual success and acceptance of biogas technology.
- Biodigester operation
  - Consistency of a feeding regime is key to the optimisation of a biodigester system.

- A biodigester should be treated like a living animal. The operator should pay attention to its changing characteristics on a daily basis.

- Loading rates and limitations should be adhered to and changed to accommodate environmental conditions (e.g. slower digest rates in cold winter months).

▪ Education and training

  - Education and training is key to the success of a biodigesters operation and a biogas programme. An inappropriately managed or used biodigester is not only a useless entity, but a detriment to the delivery of services via renewable energy and potentially damaging to the way in which alternative technologies may be perceived.

  - Training should include practical display of efficient cooking mechanisms.

▪ Technical support and maintenance

  - The questions of “who should maintain” and “how should it be orchestrated” and “who should pay” are still unanswered.

Points for discussion have been raised, and should be taken further to appropriate forums.

4.10 REFERENCE LIST

Agama Biogas (Pty) Ltd., 2010. *Agama BiogasPro Installation Manual*. Agama Energy: Cape Town.

Agama Biogas (Pty) Ltd., 2011. *Agama BiogasPro Product Data Sheet*. Agama Energy: Cape Town.

Al Seadi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., Volk, S. and Janssen, R., 2008. *Biogas Handbook*. University of Southern Denmark: Denmark.

Angelidaki, I., Lyhne, P. and Luo, G., 2013. *Methods and apparatus for hydrogen based biogas upgrading*. [Google Patents]. Available at: [http://www.google.com/patents/WO2013060331A1?cl=en] Accessed (15 January 2015).

Austin, G. and Blignaut, J.M., 2007. South African national rural domestic biogas feasibility assessment. Cape Town: AGAMA Energy (Pty) Ltd. Prepared for the Minister for Development Co-operation, The Netherlands.

Bishop-Sambrook, C., 2003. Labour saving technologies and practices for farming and household activities: Bondo and Busia Districts, Western Kenya.

Botha, J.J., van Staden, P.P., Anderson, J.J., van der Westhuizen, H.C., Theron, J.F., Taljaard, T.J., Venter, I.S. and Koatla, T.A.B., 2014. Rainwater harvesting and conservation (RWH&C) for rangeland and cropland productivity in communal areas in selected provinces in the semi-arid area of South Africa. WRC project no: K5/1775//4.

Camp, K.G.T. and Smith, J.M.B., 1997. Veld management planning in KwaZulu-Natal. Department of Agriculture, KwaZulu-Natal. Cedara report no. N/A/97/5.

Cassman, K., 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. *Proc. Natl. Acad. Sci. USA*. 96, 5952-5959.

Critchley, W., 1998. From soil conservation to sustainable land management: a new approach in Africa, in: Critchley, W., Versfeld, D., Mollel, N., (Eds.), Sustainable land management: some signposts for South Africa. The University of the North Press, South Africa, pp. 9-31.

Denison, J., Wotshela, L., 2009. Indigenous Water Harvesting and Conservation Practices: Historical context, cases and implications. WRC Report No.TT 392/09 .

Denison, J., Smulders, H., Kruger, E., Ndingi, H. and Botha, M., 2011. Water Harvesting and Conservation. Vol. 2 Part 1: Technical manual and farmer handouts. WRC Report TT 493/11.

Edmeades, D.E., 2003. The long-term effects of manures and fertilisers on soil productivity and quality: a review. *Nutrient Cycling in Agroecosystems* 66, 165-180.

Edwards, P.J., 1980. The use of stocking rate/ animal performance models in research and extension. Proceedings of the grassland society Southern Africa, 15, 73-77.

Edwards, P.J. and Mappledoram, B. D., 1979. The effects of stocking rate on beef production from star grass (*Cynodon nlemfuensis harl*). Proceedings of the grassland society Southern Africa, 14, 101-105.

Eldridge, D.J. and Green, R.S.B., 1994. Microbiotic soil crusts: a review of their roles in soil and ecological processes in the rangelands of Australia. Australian Journal of Soil Research 32, 389-415.

Everson, C.S., Mthembu, B. E. and Everson, T.M., 2012. Effect of agroforestry and intercropping systems on fodder production in rural areas of South Africa. WRC Report No.K5/1351/1-97.

Everson, T.M. and Hatch, G.P., 1999. Managing veld (rangeland) in the communal areas of southern Africa. In: Tainton NM (Ed) Veld Management in South Africa. University of Natal Press, Pietermaritzburg. 381-388.

FAO, 1988. Guidelines: land evaluation for extensive grazing. *FAO Soil Bulletin* No 58 Rome.

Fynn, R.W.S., 2012. Functional resource heterogeneity increases livestock and rangeland productivity. *Rangeland Ecology and Management* 65, 319-329.

Fynn, R.W.S. and O'Connor, T.G., 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna. *South Africa. Journal of Applied Ecology* 37, 491-507.

Gurung, J.B., 1997. Review of literature on effect of slurry use on crop production. biogas support programme. 102p. BSP Lib Temp No. 20.

Gurung, J.B., 1997. Training manual: Proper utilisation of bioslurry. BSP Lib Temp.

Gwayumba, W., Christensen, D.A., McKinnon, J.J. and Yu, P., 2002. Dry matter intake, digestibility and milk yield by Friesian cows fed two Napier grass varieties. Asian-Australasian Journal of Animal Sciences 15, 516-521.

Hardy, M. and Tainton, N., 2007. Towards a technique for determining basal cover in tufted grasslands. *Afr. J. Range. Forage. Sci*. 10(2):77-81.

Islam, M.R., Rahman, S.M.E., Islam, K.M.S. and Chowdhury, R., 2009. Effect of the application of dried slurry on yield and chemical composition of maize fodder (*Zea mays*). *Bangladesh Journal of Animal Science* 37, 52-57.

Islam, M.R., Rahman, S.M.E., Rahman, M.D.M., OH, D.H. and RA, C.S., 2010. The effects of biogas slurry on the production and quality of maize fodder. *Turkish Journal of Agriculture and Forestry* 34, 91-99.

Johnson, S.L., Adams, R.M. and Perry, G.M., 1991. The on-farm costs of reducing ground water pollution. *American Journal of Agricultural Economics* 73, 1063-1073.

Kirkman, K.P. and Moore, A., 1995. Perspective: Towards improved grazing management recommendations for sourveld. *African Journal of Range and Forage Science* 12, 135-144.

Kunene, N.W., Wilson, R.A.C. and Myeni, N.P., 2003. The use of trees, shrubs and herbs in livestock production by communal farmers in Northern KwaZulu-Natal. *African Journal of Range and Forage Science* 20, 217-274.

Le Houérou, H.N., 2000. Use of fodder trees and shrubs (TRUBS) in the arid and semi-arid zones of West Asia and North Africa (WANA): History and perspectives, in: Gintzburger, G., Bounejmate, M., Nefzaoui, A. (Eds.), Fodder Shrub Development in Arid and Semi-arid Zones. ICARDA, Aleppo, pp. 9-53.

Manssour, K.M.Y., 2011. Rangeland degradation assessment using remote sensing and vegetation species. In, School of Environmental Sciences. Pietermaritzburg, South Africa: University of KwaZulu-Natal.

Meissner, H.H., 1982. Substitution values of various classes of farm and game animals in terms of a biologically defined large stock unit. Farming in South Africa. Beef Cattle C.3/1982.

Mekdaschi Studer, R. and Liniger, H., 2013. Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; MetaMeta, Wageningen.

Ministry of Livestock Development, National Dairy Development Project (MLD), 1991. The Management of Napier grass: Zero grazing. Handbook on Technical Aspects volume 2, Ministry of Livestock Development, Nairobi, Kenya

Morris, C.D., Derry, J.F. and Hardy, M.B., 1999. Effects of cattle and sheep grazing on the structure of highland sourveld swards in South Africa. *Tropical grasslands* 33, 111-121.

Nasir, A., Khan, F.H., Riaz, M. and Khan, M.A., 2010. Comparative study of biogas slurry with farmyard manure as fertilizer on maize crop. *Science International* (Lahore) 22, 297-301.

Orodho, A.B., 2006. The role and importance of Napier grass in the smallholder dairy industry in Kenya, (Food and Agriculture Organization, Rome) Retrieved January 11, 2013 from http://www.fao.org/ag/AGP/AGPC/doc/Newpub/napier/napier_kenya.htm

Pagliai, M., Vignozzi, N. and Pellegrini, S., 2004. Soil structure and the effect of management practices. *Soil and Tillage Research* 79, 131-143.

Salomon, M., 2011. Keeping cattle in a changing rural landscape. Communal rangeland management in Okhombe, Kwazulu-Natal, South Africa. Pietermaritzburg: South Africa. University of KwaZulu-Natal. (PhD thesis)

Schreuder, R., Snijders, P.J.M., Wouters, A.P., Steg, A. and Kariuki, J.N., 1993. Variation in OM digestibility, CP, Yield and ash content of Napier grass (*Pennisetum purpureum*) and their prediction from chemical and environmental factor. Research report, National Animal Husbandry Research Station, Naivasha Kenya, pp. 62.

Schumach, K., 2002. *Pennisetum purpureum*. Perdue University. Center for New Crops and Plant Products. 2002. http://hort.purdue.edu/newcrop/duke_energy/Pennisetum_purpurium.html. 4 p.

Serna, E., 2009. *Anaerobic digestion process*. [WtERT]. Available at: [http://www.wtert.eu/default.asp?Menue=13&ShowDok=12] Accessed (07 January 2015).

Shrestha, A., 2010. Prospects of biogas in terms of socio-economic and environmental benefits to rural community of Nepal: a case of biogas project in Gaikhur VCD of Gorkha District. Degree of Masters of Science (M.Sc.) In Environment Science.

Smithers, J.C. and Schulze, R.E., 2004. The estimation of design rainfalls for South Africa using a regional scale invariant approach. *Water SA* 30(4): 435-444.

Tainton, N., 1999. Veld Management in South Africa. University of Natal Press, Pietermaritzburg.

Tau, M.S., 2005. Grazing management in the communal rangelands of the upper Thukela, KwaZulu-Natal, in School of Environmental Sciences. Pietermaritzburg, South Africa: University of KwaZulu-Natal.

van Zyl, E.A. and Dannhauser, C.S., 2005. Dry matter yield and nutritional value of companion crops, intercropped with maize, for grazing purposes in northwestern KwaZulu-Natal. *African Journal of Range and Forage Science* 12, 135-144.

Vetter, S., 2013. Development and sustainable management of rangeland commons aligning policy with the realities of South Africa's rural landscape. *African Journal of Range and Forage Science* 30, 1-9.

Vetter, S. and Bonds, W.J., 2012. Changing predictors of spatial and temporal variability in stocking rates in a severely degraded communal rangeland. *Land Degradation and Development* 23, 190-199.

Von Maltitz, G., 1998. Communal rangeland management options for the Okhombe community. In: Proc. of symposium on policy-making for the sustainable use of southern African communal rangelands. University of Fort Hare, Alice: 68-74.

4.11 IMAGE AND FIGURE REFERENCES

Author/website	Date	Name	Available at	Access date
'Antoniraj' on instructables.com	2015	Mini Bio-gas plant using food waste, decomposable organic material and kitchen waste	http://www.instructables.com/id/Bio-gas-plant-using-kitchen-waste/	2015-02-01
Biogas Plant (AD) Blog	2015	Biogas Plant Photos	http://bio-gas-plant.blogspot.com/p/biogas-plant-photos.html	2015-02-01
Biogas Technology	2011	Biogas Plan Photos Pakistan – Movable dome plant	http://biogas-technology.blogspot.com/2013/03/biogas-plant-photos-pakistan.html	2015-01-15
Burton M	2014	Biogas digester 001	http://www.michaelburtonsr.com/wp-content/uploads/2014/11/Biogas-Digester-Digester-01.jpg	2015-01-15
Energypedia	2010	Biodigestor familiar bolivia altiplano	https://energypedia.info/wiki/File:Biodigestor_familiar_bolivia_altiplano.jpg	2015-01-15
Energypedia	2009	Camartecfixdome.gif	https://energypedia.info/wiki/File:Camartecfixdome.gif	2015-01-15
JoJo Tanks	2015	JoJo Website	http://www.jojotanks.co.za/	2015-02-01
Lebofa M	2006	WG3 Fixed dome digester during construction, Lesotho	https://www.flickr.com/photos/gtzecosan/6730176911/	2015-01-15
Linea Tyre Industry Limited	n.d.	Natural tube	http://www.leinatyre.com/Product.asp?ClassID=57	2015-02-01
Takamoto Biogas	2011		http://www.takamotobiogas.com/wp-content/uploads/2011/10/IMG_2786sm.jpg	2015-0115
Tangka J	2010	Fixed dome digester training with ADEID in Bafut Cameroon	http://www.juliustangka.org/apps/photos/photo?photoid=77812763	2015-01-15
Technology Times	2011	Biogas plant Kerala	http://www.technologytimes.pk/wp-content/uploads/2011/05/Biogas_plant_Kerala.jpg	2015-01-15
Weatherford V	2010	Biogas – Travelogues and Meetups	http://biogas.wikispaces.com/Travelogues+and+Meetups	2015-01-15

9781431207336