The Potential of Small-Scale Biogas Digesters to Improve Livelihoods and Long Term Sustainability of Ecosystem Services in Sub-Saharan Africa

Second Quarterly Report – 19/08/12

<u>Organisations</u>

University of Aberdeen (UA)
Makerere University (MU)
James Hutton Institute (JHI)
Scottish Agricultural College (SAC)
Green Heat Uganda (GHU)
Orskov Foundation (ORS)

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Introduction

This project aims to provide information that will help the success of national programmes to establish biogas digesters in Sub-Saharan Africa (SSA). It will investigate key questions as to the potential of alternative cheaper designs of digester to encourage wider uptake of the technology amongst the poorest members of a community and to provide a long-term energy supply and effective treatment of organic wastes, the need for adaptation of cooking equipment and farming systems to accommodate biogas technology, and economic returns from digesters. In order to do this, we are installing 9 of the cheapest available design, flexible balloon biogas digesters, in the village of Tiribogo, Muduuma Sub-County, Mpigi district, near Kampala, Uganda, and investigating changes in socioeconomics, resource use and health associated with the installations. We have also installed one digester at the Makerere University experimental station at Kabanyolo and will study in detail the changes in resource use using field trials. The information gathered during the project will be summarised in a simple model of the system to allow the conclusions from Tiribogo to be extrapolated to a wider context.

Project structure

The work addresses the 3 key questions

1. What is the potential of flexible-balloon digesters in SSA?
2. What changes are needed in farmer attitudes, equipment and design of farming systems?
3. What is the value of a biogas digester in terms of energy, organic fertiliser, reduction in deforestation, improved sanitation and improved household air quality?

The work is focussing on the Ugandan programme because it is already well underway; we have strong links with the programme as well as newly established companies, providers of digesters; and partners at MU provide strong expertise in biogas in Uganda. The questions are being tackled by three MSc students (two registered at MU and one at UA), and one research assistant. The students and research assistant are working together at sites situated at one village, the village of Tiribogo, Muduuma Sub-County, Mpigi district, near Kampala, Uganda. By focusing efforts in just one location, a solid foundation for the spread of the technology will be created. The work aims to create a model approach for seeding the technology that can be used in other areas of Uganda and other countries in SSA.

The potential of flexible-balloon digesters in SSA is being considered by MSc1 registered at MU, focusing on Tiribogo, but also taking in the surrounding area to give context to the work at Tiribogo. Site selection, installation and engineering issues, energy flows and design of equipment and farming systems are being considered by MSc2 registered at UA. The impact of biogas digesters on resource flows (nutrients, carbon and water) are being investigated by MSc3 registered at MU, and the impact on household air quality and exposure to pathogen are being measured by the research assistant, RA1 from UA. Nine of the sites where biogas digesters are installed and studied by MSc2, MSc3 and RA1 are in Tiribogo and one is at the MU experimental station at Kabanyolo. An economic value will be assigned by MSc1 to the changes in resource flows and health induced by the biogas digester.

Achievements from the first quarter

In the first quarter, detailed work plans were drawn up by the three MSc students and RA1. Moris Kabyanga (MSc1) completed training at MU and made good progress on selecting households and preparation work for the baseline survey. This socioeconomic work was slightly delayed due to financial and administrative difficulties, but these difficulties have now been addressed. Swaib Semiyaga (MSc3) and Andrew Apsley (RA1) received training in Aberdeen and initiated research work and ordering of equipment and consumables ready to start baseline measurements. Vianney Tumwesige (MSc2) selected the 9 households where biogas digesters would be installed and completed a detailed review for sourcing biogas digesters in Uganda. An important issue encountered in the first quarter was the difficulty of sourcing flexible balloon biogas digesters in Uganda, resulting in higher prices than expected and longer delivery times. This has resulted in the need to reorganise the work in the second quarter, but all objectives remain on target.

Milestones for second quarter

A full list of all project activities is given in appendix A. The milestones included in the work of the second quarter are given below. The sections below detail the progress that has been made in each of these milestones. Many changes in the detailed work plans have been made due to difficulties with delivery of equipment. However, the overall work plan and milestones remain on course for timely completion.

Objective 1. What is the potential of flexible-balloon digesters to alleviate poverty in SSA?

Milestone 1.1. Sociological and economic research to identify villages in regions where implementation of flexible-balloon digesters will be piloted (MSc2 – Delivery date = 31/05/12). *Status – complete – see 1st quarterly report.*

Milestone 1.2. Socioeconomic analysis, exploring cost/benefits and willingness to pay (MSc1 - Delivery date = 19/02/13). *Status – baseline survey complete; analysis of data underway.*

Objective 2. What changes are needed in design of equipment and farming systems to optimise returns of energy and agricultural products from the biogas digester / farming system?

Milestone 2.1. Installation of flexible balloon biogas digesters (MSc2 - Delivery date = 30/06/12). *Status – installation of one digester at Kabanyolo experimental station completed following air-freight for speed. Remaining 9 digesters have arrived at Mombasa and waiting customs clearance and trans-shipping to Kampala. Expected installation – 09/12.*

Milestone 2.2. Provide training to local people on installation of flexible-balloon biogas digesters (MSc2 - Delivery date = 30/06/12). *Status - delayed due to delay in digester installation.*

Milestone 2.3. Document engineering problems associated with technical implementation (MSc2 - Delivery date = 30/06/12). *Status - delayed due to delay in digester installation.*

Milestone 2.4. Establish trials to identify optimum return of agricultural products from applied nutrients (MSc3 - Delivery date = 31/07/12). *Status – design of trials complete.*

Objective 3. What is the value of a biogas digester?

Milestone 3.1. Training in measurement techniques for measurement of carbon, nutrients, energy and water flows (MSc3 – Delivery date 31/05/12). *Status – complete – see 1st quarterly report.*

Milestone 3.2. Measurement of carbon and nutrients, energy and water use before establishment of biogas digesters (MSc3 – Delivery date 31/05/12). *Status – Delayed - procurement of consumables ongoing*

Milestone 3.3. Measurement of carbon, nutrients, energy and water flows in trials (MSc3 – Delivery date 31/07/12). *Status - Delayed due to delay in digester installation – plots have been prepared for trials*

Milestone 3.5. Training in measurement techniques for measurement of pathogen distribution and household air quality (RA1 – Delivery date 31/05/12). *Status – complete – see 1st quarterly report.*

Milestone 3.6. Measurement of pathogen distribution and household air quality before installation (RA1 – Delivery date 31/05/12). *Status – household air quality measurements complete; pathogen measurements delayed due to non-delivery of equipment and consumables.*

Milestone 3.7. Measurement of pathogen distribution and household air quality in trials (RA1 – Delivery date 31/07/12). *Status – delayed due to delay in digester installation.*

Objective 4. User engagement

Milestone 4.4. Present results of research to local people and downstream users in an accessible way (Delivery date 20/02/13). *Status – version 1 of information booklet produced and currently being translated.*

MSc1- Socio-economic research into the potential of small scale biogas digesters to improve livelihoods in Sub-Saharan Africa

General description and revised work plan

The research included in MSc1 will provide socio-economic analyses, exploring costs and benefits of a small-scale biogas digester in a rural setting. Measurements of resource flows (detailed below) will provide a basis for the full economic value of digesters to householders to be quantified. The work will identify factors determining uptake of biogas digesters and assign values to the different costs and benefits that can be used by MSc2 in systems modelling. The work of the first quarter was delayed due to financial and administrative difficulties associated with the retrospective mode of payment of funds. Because of the current financial climate, MU finds it difficult to make funds available to the project in advance of payments. Therefore, UA advanced the funds to MU, but there were administrative delays in making this transfer. The impact of these delays was to delay the baseline survey and data entry by approximately six weeks. The revised work plan is shown in table 1.

Table 1 – Revised work plan for MSc1

<table>
<tr><th>Date</th><th colspan="3">Task</th></tr>
<tr><td>05/03/2012</td><td rowspan="13">Literature survey</td><td rowspan="4" colspan="2">Household selection for socio-economic survey</td></tr>
<tr><td>12/03/2012</td></tr>
<tr><td>19/03/2012</td></tr>
<tr><td>26/03/2012</td></tr>
<tr><td>02/04/2012</td><td rowspan="9" colspan="2">Design of questionnaire for the socio-economic baseline survey</td></tr>
<tr><td>09/04/2012</td></tr>
<tr><td>16/04/2012</td></tr>
<tr><td>23/04/2012</td></tr>
<tr><td>30/04/2012</td></tr>
<tr><td>07/05/2012</td></tr>
<tr><td>14/05/2012</td></tr>
<tr><td>21/05/2012</td></tr>
<tr><td>28/05/2012</td></tr>
<tr><td>04/06/2012</td><td rowspan="9">Field survey</td><td rowspan="9" colspan="2">Questionnaire pre-testing

Baseline survey</td></tr>
<tr><td>11/06/2012</td></tr>
<tr><td>18/06/2012</td></tr>
<tr><td>25/06/2012</td></tr>
<tr><td>02/07/2012</td></tr>
<tr><td>09/07/2012</td></tr>
<tr><td>16/07/2012</td></tr>
<tr><td>23/07/2012</td></tr>
<tr><td>30/07/2012</td></tr>
<tr><td>06/08/2012</td><td rowspan="8">Cost items identified and quantified</td><td rowspan="8">Benefit items identified and approaches to quantification outlined</td><td rowspan="8">Description of the study area (farming systems, perception,...) via talking to people, visits, secondary data</td></tr>
<tr><td>13/08/2012</td></tr>
<tr><td>20/08/2012</td></tr>
<tr><td>27/08/2012</td></tr>
<tr><td>03/09/2012</td></tr>
<tr><td>10/09/2012</td></tr>
<tr><td>17/09/2012</td></tr>
<tr><td>24/09/2012</td></tr>
<tr><td>01/10/2012</td><td rowspan="2" colspan="3">Entry and analysis of baseline data, completion of report on baseline survey and preparation of data collection tools for follow-up survey</td></tr>
<tr><td>08/10/2012</td></tr>
</table>

Date	Task
15/10/2012	
22/10/2012	
29/10/2012	
05/11/2012	
12/11/2012	
19/11/2012	
26/11/2012	
03/12/2012	Second round survey
10/12/2012	
17/12/2012	
24/12/2012	
31/12/2012	
07/01/2013	Analysis and write-up
14/01/2013	
21/01/2013	
28/01/2013	
04/02/2013	Final thesis
11/02/2013	
18/02/2013	

Progress towards socioeconomic analysis, exploring cost/benefits and willingness to pay (1.2)

Literature survey

Collated literature has been used to develop the questionnaire for the baseline survey. Other literature has been used to draft the student's project proposal. Work on the project proposal and the literature review is still ongoing.

Household selection for socio-economic survey

It was initially planned that 270 households would be included in the sampling frame. A sample of 150 would then be selected from the sampling frame using a random sampling approach. The sampling approach planned to list male and female headed households in separate lists, arranged in alphabetical order, and then select a random sample from each of these numbered lists to meet the total sample size of 150. In practice there were insufficient households to follow this procedure and so most households in the sampling frame were included in the survey.

The steps followed in preparation for the baseline survey were as follows:

- Pre-test of the questionnaire. Information collected was used to adjust the questionnaire to be more suitable for use with farmers.
- Meeting with the local field guide to discuss organisation of the survey to reduce the respondent burden.
- Meeting with area leaders to draw up a village list that would be used to randomly select the respondents.
- Discussion of the sampling approach with the field guide to ensure selection criteria were met.

Baseline survey

The baseline survey has been successfully completed, with a total of 150 households interviewed by MSc1, assisted by three enumerators. Fig. 1 shows interviews being carried out in Tiribogo by the team.

Figure 1 - Baseline interviews for the socioeconomic analysis being carried out by the team in Tiribogo

Data entry and analysis

Coding of the data is complete and a template for data analysis has been developed. Data entry and analysis are expected to be completed by first week of September.

Expenditure

Expenditure for the activities of MSc1 are given in table 2.

Table 2 – Expenditure up to 19/08/12 for MSc1

Item	Amount spent UGX	£
[A] Pretesting the survey instrument		
Per diem for MSc student and supervisors	1,310,000	338
Transport expenses (vehicle hire and fuel)	600,000	155
Stationery and photocopying	43,000	11
Sub-total	**1,953,000**	**504**
[B] Baseline survey expenditure		
Per diem for MSc. Student, field guides, enumerators and supervisors	6,170,000	1,592
Communication (air time)	110,000	28.38
Transport expenses (vehicle hire and fuel)	3,360,000	867
Stationery and photocopying services	570,000	147.06
Refreshments for respondents	330,000	85.14
Administrative/Institutional fees	646,152	166.707216
Sub-total	**11,186,152**	**2,886**
Total [A] + [B]	**13,139,152**	**3,390**
Exchange rate (UGX -> £)	0.000258	

MSc2 - Systems analysis of the potential of flexible balloon digesters to improve livelihoods and long term sustainability of ecosystem services in Sub-Saharan Africa

General description and revised work plan

Flexible-balloon digesters are to be installed at 10 selected sites (9 in households in Tiribogo; 1 at an experimental site at MU, Muarik Makerere University Agricultural Research Institute, Kabanyolo). Training will be provided to local people during and following installation, with a view to establishing spin-off companies that will be able to provide future access to digesters in the locality. Training will be provided on condition that each trainee provides further training for at least two more people in surrounding communities, who will in turn agree to provide further training in further communities. It is intended that this approach will facilitate the growth of locally run businesses that will disseminate and maintain the technology.

The engineering problems associated with technical implementation will be documented and addressed; the biogas digesters should be affordable, use local materials where possible, and provide efficient biogas production and a fully digested safe organic fertiliser. Problems of sourcing the durable plastics usually used in flexible balloon digesters have already been encountered. Issues include quantity of plastic that must be ordered at one time, making start-up costs prohibitive for a new small-scale business. A reliable source has been identified, but was more costly than expected and introduced delays due to shipping times. One digester was air freighted for installation at Kabanyolo to allow the trial at the experimental site to start on time. However, the remaining nine digesters were shipped to avoid the high cost of air freight. This has required the work plan for installation of the digesters in Tiribogo be revised as shown in table 3 and has impacted the timing of tasks undertaken by MSc3 and RA1.

Because the period of work in Uganda for RA1 will now finish before the digesters have been installed, MSc2 will also complete the microbiological sampling and air quality analysis after the digesters have been installed. This adds value to the training provided to MSc2 and will be facilitated by

1. thorough preparation of equipment and facilities by RA1,
2. a visit to Uganda by Lisa Avery to provide additional training for MSc2,
3. completion of some of the modelling work by Jo Smith in advance of the period when MSc2 will visit the UK to complete the modelling and systems analysis tasks.

While waiting for the biogas digesters to be delivered, further progress has been made on other milestones. Drafting of publicity information and a manual that will be provided with each system to explain installation and help people to understand the value of the digester is underway. This information is highly graphical and explains processes of installation, benefits, what is happening in the digester and potential problems. The manual will be made available in electronic format so that it can be printed out as posters for use with communities or as a book to be used by each household where a digester is installed.

Households within Tiribogo where the biogas digesters will be installed have been selected by a systematic process as described in the 1st quarterly report. A comprehensive time-management analysis will be completed at these sites to determine potential labour savings and improved designs of cooking equipment and farm layout. The farm-gate inputs of energy will be estimated through a questionnaire. The questionnaire has been designed and used to provide a baseline survey. Energy production by the biogas digester will be measured using analogue gas flow meters. Measurements of resource flows in MSc2 will provide a further basis for improvements to the design of equipment and farming systems. A risk assessment will also be completed during each installation. This aims to avoid any significant risks associated with installation of biogas digesters.

The potential uses of digested slurry to be investigated may include direct application to crops, composting and use as a substrate in aquaculture. The uses to be investigated will depend on the preferences of the farmer; a farmer with a small area of cash crops may prefer to apply bioslurry directly to the crops on a daily basis whereas a farmer with a larger area of crops may prefer to compost the bioslurry with less nutrient rich organic wastes to increase the volume of compost available. A questionnaire has been completed at the 9 trial sites by MSc3 to determine preferred uses of bioslurry, allowing appropriate trials to be designed. Trials will be set up to identify optimum return of agricultural products from applied nutrients. Systems modelling will be used to integrate results to provide an estimate of the potential regional improvement in water quality, crop production and carbon sequestration.

Modelling will also be used to identify regions where digesters are likely to be most beneficial to the rural community. Initial results from MSc1, MSc3 and RA1, and data from the literature will be collected for use in the systems modelling. From December to end of February, training in systems modelling will be provided at UA by Jo Smith. A simple model will be devised that can be used to determine the value of a biogas digester to the household, as well as scaling up to determine the value to the wider community at regional scale.

Table 3 – Revised work plan for MSc2

<table>
<tr><th>Date</th><th colspan="3">Task</th></tr>
<tr><td>05/03/2012</td><td rowspan="17">Source digesters & literature review</td><td rowspan="4">Design baseline survey with MSc1, MSc2 and RA1</td><td rowspan="30">Documentation of engineering problems and time management analysis</td></tr>
<tr><td>12/03/2012</td></tr>
<tr><td>19/03/2012</td></tr>
<tr><td>26/03/2012</td></tr>
<tr><td>02/04/2012</td><td rowspan="11">Selection of farmers</td></tr>
<tr><td>09/04/2012</td></tr>
<tr><td>16/04/2012</td></tr>
<tr><td>23/04/2012</td></tr>
<tr><td>30/04/2012</td></tr>
<tr><td>07/05/2012</td></tr>
<tr><td>14/05/2012</td></tr>
<tr><td>21/05/2012</td></tr>
<tr><td>28/05/2012</td></tr>
<tr><td>04/06/2012</td></tr>
<tr><td>11/06/2012</td></tr>
<tr><td>18/06/2012</td><td rowspan="2">Installation of digester at Kabanyolo</td></tr>
<tr><td>25/06/2012</td></tr>
<tr><td>02/07/2012</td><td rowspan="5">Collect together data and information for use in systems modelling</td><td rowspan="5">Setup trials at Kabanyolo with MSc3</td></tr>
<tr><td>09/07/2012</td></tr>
<tr><td>16/07/2012</td></tr>
<tr><td>23/07/2012</td></tr>
<tr><td>30/07/2012</td></tr>
<tr><td>06/08/2012</td><td rowspan="3">Setup trials with MSc3</td><td rowspan="3">Training in microbial and household air quality techniques</td></tr>
<tr><td>13/08/2012</td></tr>
<tr><td>20/08/2012</td></tr>
<tr><td>27/08/2012</td><td rowspan="5">Installation of biogas digesters at selected sites</td><td rowspan="5">Training of farmers in installation, maintenance and value of digesters</td></tr>
<tr><td>03/09/2012</td></tr>
<tr><td>10/09/2012</td></tr>
<tr><td>17/09/2012</td></tr>
<tr><td>24/09/2012</td></tr>
<tr><td>01/10/2012</td><td colspan="3" rowspan="4">Setup trials at Tiribogo with MSc3</td></tr>
<tr><td>08/10/2012</td></tr>
<tr><td>15/10/2012</td></tr>
<tr><td>22/10/2012</td></tr>
<tr><td>29/10/2012</td><td>Visit C - sites 1-5</td><td rowspan="2">Micro.sampling - after installation</td><td rowspan="4">Air sampling (2 homes / week)</td></tr>
<tr><td>05/11/2012</td><td>- sites 6-9</td></tr>
<tr><td>12/11/2012</td><td>- sites 10-14</td><td rowspan="2">Micro.sampling - no installation</td></tr>
<tr><td>19/11/2012</td><td>- sites 15-18</td></tr>
</table>

Date	Task		
26/11/2012	Data analysis		
03/12/2012			
10/12/2012			
17/12/2012			
24/12/2012	Debrief and clean-up		
31/12/2012	Prepare for trip to Aberdeen		
07/01/2013	Training and application of systems analysis at UoA.	Analysis and write-up	Final thesis
14/01/2013			
21/01/2013			
28/01/2013			
04/02/2013			
11/02/2013			
18/02/2013			

Installation of flexible balloon biogas digesters (2.1)

Sourcing of biogas digesters

Because of the difficulties associated with obtaining flexible balloon biogas digesters in Uganda, the cost of the digesters is somewhat higher than was anticipated during the project planning. The digesters have been obtained from Arjan Coenradie of the ChangeIT Foundation (info@changeitfoundation.com). The planned and expected costs of biogas digesters with volume $8m^3$ and made from the more robust 850 g m^{-2} grade plastic are shown in table 4.

This is consistent with other quotations received for Africa (8 m^3 digester from C&F Kampala = £209/unit plus shipping costs – quality unknown; 6 m^3 digester from a Kenyan company, Biogas International, (http://www.biogas.co.ke/) = £437.12). There is a need to understand the reason for the relatively high costs of these digesters in SSA and to look for opportunities to reduce these costs.

The additional funding required for the biogas digesters will be obtained from saved funding due to a mini wind tunnel no longer being required on the project (see work plan for MSc3, below).

Table 4 - Increased expenditure on biogas digesters

Item	Planned expenditure	Expected actual expenditure	Comment
1 x $8m^3$ anaerobic digesters made from 850 g m^{-2} grade plastic	£60	£335	Reason for increased cost is the difficulty in sourcing the materials for biogas digesters in Uganda compared to other parts of the world
Number of digesters	10	10	
Total cost for digesters	£600	£3350	Difference in cost will be accommodated through savings in other parts of the project

The development of low cost biogas digesters using agricultural wastes will continue to be led by private sector, but with government assistance. The scale of projects should be relatively small in order to make them affordable to the average family or community. However, the development of larger scale production and distribution of flexible balloon digesters are probably out of reach of the average local investor.

Removal of barriers to uptake could be addressed by:

(a) **Improved tax incentives for renewables.** The Ugandan government needs to take action to remove existing policy barriers and make renewable energy developers eligible for tax and import duty exemptions and special tax deductions. *ACTION: A summary report will be produced at the end of this project and sent to the appropriate government departments.*

(b) **Institutional strengthening of rural financial institutions.** There is a need to train the rural financial institutions in understanding and appraising renewable energy systems (biogas digesters) and develop a sound capacity to evaluate the viability of biogas projects for financing, monitor their performance, and debt collection. *ACTION: An information sheet will be produced at the end of the project aimed at rural financial institutions. This will be sent to Ugandan institutions that might have an interest in funding biogas digesters and made available on the web.*

(c) **Promote technology for manufacturing biogas components.** There is a need to promote local manufacturing of high-quality components and related management expertise to improve overall efficiency of biogas production facilities. *ACTION: An information sheet will be produced at the end of the project aimed at local manufacturing businesses. This will be sent to a number of Ugandan businesses, identified as having an interest in manufacturing parts for biogas digesters. It will also be made available on the web.*

(d) **Promote additional barrier removal**. Issues to be addressed include VAT, taxes, and additional tax incentives. *ACTION: Recommendations for facilitating uptake biogas digesters will be included in the report sent to government departments.*

Installation of digester at Kabanyolo

System description

The biogas digester that has been installed is of the plug-flow type (Fig. 2). It consists of a bag with an elongated shape, with a length to width ratio of about 5:1. The wet organic waste is fed into one end of the digester and the effluent material comes out the other. The bag (digester) is mounted in a shallow ditch which supports the digester (bag) with the feedstock contained within it. The biogas produced bubbles out of the decomposing organic waste and is stored in the upper part of the bag. The gas is piped from the bag through a gas connection on top, and from there it is piped into the kitchen. In its least complex form, there are no systems for stirring or heating up the contents of the digester.

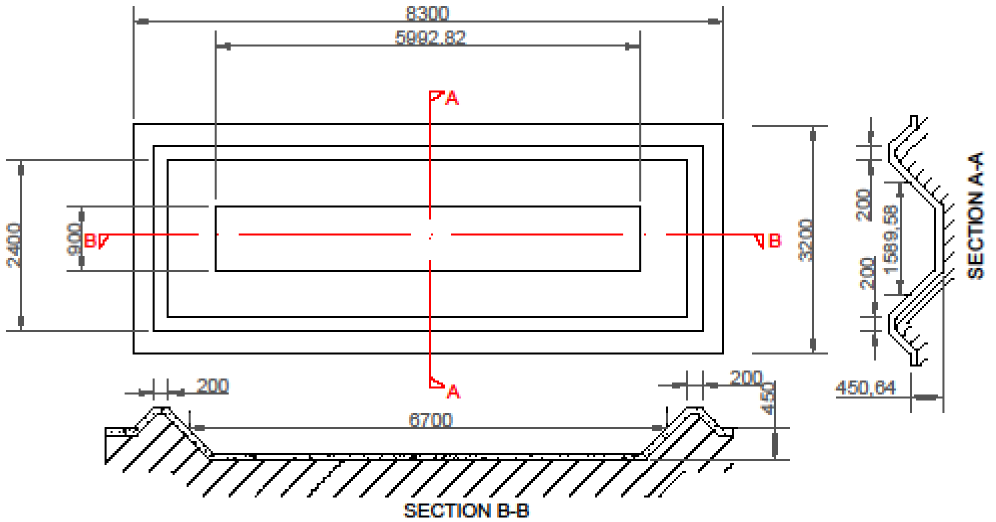

Figure 2 - Cross section of the plug-flow digester

The system is typically used for the digestion of animal manure and other organic matter. Any mixture should have dry matter content below 15% in order to flow through (Arjan Coenradie, ChangeIT Foundation, pers. comm.). For some types of feedstock, this means that water needs to be added to the mixture. The slurry occupies approximately 60-70 % of the digester volume; the remaining space is for gas storage (Arjan Coenradie, ChangeIT Foundation, pers. comm.). At average ambient temperatures of 25-30 °C, typical retention times are in the order of 40 days; this implies that the daily material input in litres should be $1/40^{th}$ of the wet volume of the digester. Therefore, an 8 m^3 digester has a potential slurry content of 4.8 – 5.6 m^3 and should be fed with 120 – 140 litres of wet feedstock each day.

Installation description

A list of the items required for installation of the biogas digester is provided in table 5 and depicted in Fig. 3.

Table 5 - List of items required to install the biogas digester

Item	Description
Digester Bag	Reinforced PVC, 0.85 kg/m2 (thickness) with standard flat dimensions: 6 x 2.6, Gas connection 1" thread
Inlet pipe	Diameter - 110mm PVC pipe with a 1.5m length
Outlet pipe	Diameter - 110mm PVC pipe with a 1.5m length
Fastening materials	30mm rubber strips from a car inner tube (8 m) and clamps
Hose pipe	1/2" hose pipe - 10m
Funnel	1 piece
Shovels	For ground work
Rope and pegs	Thin ropes (50m) and pegs for marking ground works
Measuring tape	For measuring excavation works etc
Sand paper	For rounding off inlet and outlet pipes

Figure 3 – Tools and materials used to install the biogas digester

The first step in the installation is the selection of the site. The site selected should be large enough for the digester bag, the inlet and outlet of the digester, and have additional space to enable the operator to walk around the installation. The ground should also be flat or slightly sloped. A position was selected on flat ground, close to the kitchen of the household hosting the digester at Kabanyolo experimental station.

After selecting a suitable location, a ditch was dug in the position chosen for the digester bag. The soil from the ditch was heaped around the ditch; this created a low wall which increased the effective depth of the ditch. A sketch of the ditch and its dimensions is given in the Fig. 2.

The ditch was dug in two phases (Fig. 4):

1. A ditch with vertical walls was dug, with the dimensions of the digester bag. Corners and sides of the ditch were marked with pegs and ropes. The soil from the ditch was put far enough from the edge of the ditch to allow the extension to avoid caving in.

2. To prevent the ditch from caving in, the sides were scraped off diagonally at an approximate angle of 45 degrees, arriving at the final dimensions of the ditch.

Figure 4 - Excavation of an 8m^3 digester ditch

Figure 5 - Root on the sides of the ditch

Care was taken to ensure that there were no sharp rocks or roots from trees or plants in the bottom or sides of the ditch as these sharp objects could easily damage the digester bag (Fig. 5).

When the ditch was complete, the digester bag was placed inside with the gas connectors on top (Fig. 6). The inlet and outlet pipes were installed and fixed at an angle which allowed both the feedstock and slurry to move in and out of the digester.

Figure 6- Digester bedded into the ditch

Starting up the digester

The digester was filled with 2.5 t of fresh cow manure mixed with 3000 litres of water; feeding the digester took two days. This batch was left for one week to allow the bacterial breakdown and biogas generation to begin.

After one week, the digester was inspected for any leakages. Two areas were identified with unwelded sections. These faulty points were glued with PVC cement and then taped (Fig. 7, 8 and 9).

Figure 7 - Un-welded point on a digester

Figure 8 - Glue applied to fix the digester

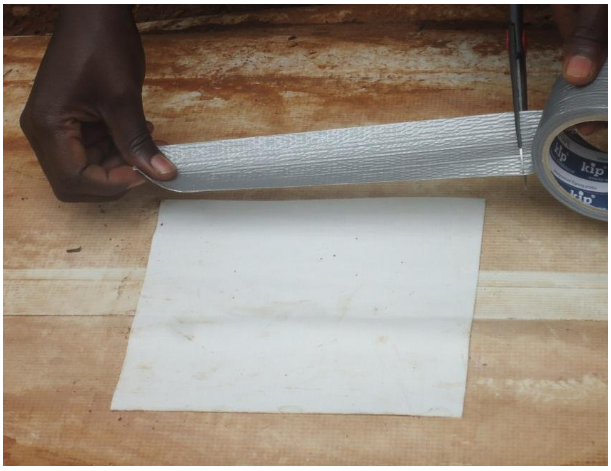

Figure 9 – Taping the glued section

Initially, mainly carbon dioxide is produced, so any gas produced in the first weeks will not burn. However, the methane content of the gas increases as more gas is generated (Fig. 10). The gas will be tested for flammability in the next month.

Figure 10 - Digester generating gas

Possible issues

The only issue that has been encountered to date is the bending of the pipe that transports the gas from the digester to the kitchen (Fig. 11). This could easily lead to blockage of the gas line and care must be taken to avoid this. An improved design might include a pipe that is resistant to bending at this point.

Figure 11 – Potential problem - bend in gas line leading to blockage

Planned installation of digesters at Tiribogo

As soon as the digesters have been retrieved from customs, they will be tested for any un-welded areas. These points will be glued together with PVC cement. In Tiribogo, the community have already started stockpiling cow dung to initialise the digesters. Dimensions of the digester ditch will be provided to the 9 householders during the last week of August. This will speed up installation by ensuring the ditches are dug before the digesters arrive.

Planning and training in installation, experimental techniques and systems modelling (2.2)

Training of selected villagers in installation and maintenance of digesters will be completed during installation of the digesters in Tiribogo. Training in systems modelling will be completed at the UA between December 2012 and February 2013.

Expenditure

Expenditure to date from this part of the work is itemised in Table 6.

Table 6 – Expenditure up to 19/08/12 for MSc2

ITEM	COST UGX	£
2 trips to Tiribogo for site selection	40,000	10.33
Printing questionnaire	140,000	36.16
Facilitation of enumerators	210,000	54.23
Trip to Tiribogo to administer questionnaires with enumerators	20,000	5.17
Trip to Tiribogo to announce successful householders	20,000	5.17
Delivery of letter requesting tax exemption	15,000	3.87
Transporting digester 1 from airport	100,000	25.83
Storage and Handling of digester at airport	69,740	18.01
Clearing agent	300,000	77.48
Fuel to Kabanyolo and Tiribogo	250,000	64.56
Digester fittings	120,000	30.99
TOTAL	1,284,740	331.79
Exchange rate (UGX -> £)	0.000258	

MSc3 - The potential impact of small scale biogas digesters on resource use and the environment in Sub-Saharan Africa

General description and revised work plan

A whole farm analysis of inputs, outputs and flows of carbon, nitrogen, phosphorus and potassium will use farm-gate inputs and outputs, estimated through a questionnaire as well as from measurements taken on the selected farms. Possible uses of bioslurry have been discussed with farmers to determine the uses that fit in with the requirements of each particular household. On-site experiments to quantify resource flows associated with the different uses favoured by the 9 farmers have been designed. A more controlled trial has been established at the MU experimental site at Kabanyolo. Baseline measurements will be taken before sowing. The experiments at 9 farms will include 3 replicates with and without treatment and using the normal practice of applying chicken manure (total = 81 samples). Three farms will be sampled each day, requiring 3 days to complete all sampling and a further 2-3 days of laboratory analysis. The experiments will be set up to take the first set of measurements in September, followed by monthly measurements until the end of December. Initial and final measurements will provide a soil characterisation, determining bulk density, clay content, total carbon, nitrogen, phosphorus and potassium. The monthly measurements will include pH, soil water, labile phosphorus, nitrate, and ammonium. In addition, RA1 will be measuring climate data; rainfall and temperature (minimum, maximum and average) in Tiribogo. Crop yields will be measured at harvest.

Three weeks out of every month are used for running the trial at Kabanyolo. The trial includes increasing rates of bioslurry and water. Measurements will be taken each month to characterise resource flows.

Soil samples and gas samples will be analysed at MU where possible. Further analysis will be done by sending samples to UA. Flows will be quantified by measuring the carbon, nitrogen, phosphorus and potassium contents of organic wastes, the amount of organic wastes fed to the digester and soil, changes in soil carbon, nitrogen, phosphorus and potassium, and the carbon and nitrogen content of biogas. Total nitrogen and carbon contents of soil and incorporated residues will be determined on a C/N analyser coupled to a SerCon 20/20 isotope ratio mass spectrometer. Gaseous losses of CO_2, CH_4, N_2O and NH_3 will be measured more frequently immediately after application, and total annual losses estimated by a combination of integration and modelling. Closed flux chambers will be used to sample gaseous losses of CO_2, CH_4 and N_2O, with analysis by gas chromatography. NH_3 emissions will be trapped in a boric acid indicator solution in a sealed chamber, allowing the concentration to be determined by back titration using 0.01 N hydrochloric acid. Losses in runoff of NO_3^-, dissolved organic matter and particulates will be measured during periods of rainfall. Total P and inorganic N in soil (NH_4^+, NO_2^- and NO_3^-) will be measured by flow injection analysis after extraction from soil in 1M KCl. Bioavailable P will be determined by extraction with acetic acid followed by colorimetric analysis. The farm-gate inputs of water will also be estimated through a questionnaire. Local weather data on rainfall and evapotranspiration will be used to determine a water balance for the farm.

Due to delays in the installation of biogas digesters, the detailed work plan for MSc3 has been modified to allow for later installation of digesters. The delays have allowed more thorough preparation for the trials. The revised work plan is shown in table 7.

Table 7 – Revised work plan for MSc3

<table>
<tr><th>Date</th><th colspan="2">Task</th></tr>
<tr><td>05/03/2012</td><td>Prepare for trip to UoA</td><td rowspan="4">Design baseline survey with MSc1, MSc2 and RA1</td></tr>
<tr><td>12/03/2012</td><td rowspan="6">Training at the UoA</td></tr>
<tr><td>19/03/2012</td></tr>
<tr><td>26/03/2012</td></tr>
<tr><td>02/04/2012</td><td rowspan="3"></td></tr>
<tr><td>09/04/2012</td></tr>
<tr><td>16/04/2012</td></tr>
<tr><td>23/04/2012</td><td colspan="2" rowspan="2">Exams and further training at MU</td></tr>
<tr><td>30/04/2012</td></tr>
</table>

<table>
<tr><th>Date</th><th colspan="2">Task</th></tr>
<tr><td>07/05/2012</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>14/05/2012</td></tr>
<tr><td>21/05/2012</td></tr>
<tr><td>28/05/2012</td></tr>
<tr><td>04/06/2012</td><td colspan="2" rowspan="4">Interview farmers at selected sites to find out how they want to use bioslurry</td></tr>
<tr><td>11/06/2012</td></tr>
<tr><td>18/06/2012</td></tr>
<tr><td>25/06/2012</td></tr>
<tr><td>02/07/2012</td><td colspan="2" rowspan="4">Decide on experimental design</td></tr>
<tr><td>09/07/2012</td></tr>
<tr><td>16/07/2012</td></tr>
<tr><td>23/07/2012</td></tr>
<tr><td>30/07/2012</td><td colspan="2">Baseline measures at sites before sowing</td></tr>
<tr><td>06/08/2012</td><td rowspan="4">Setup trials with MSc2</td><td rowspan="4">Baseline measures for trials at MU experimental site</td></tr>
<tr><td>13/08/2012</td></tr>
<tr><td>20/08/2012</td></tr>
<tr><td>27/08/2012</td></tr>
<tr><td>03/09/2012</td><td colspan="2">September measurements at sites</td></tr>
<tr><td>10/09/2012</td><td colspan="2" rowspan="3">September measurements on trails</td></tr>
<tr><td>17/09/2012</td></tr>
<tr><td>24/09/2012</td></tr>
<tr><td>01/10/2012</td><td colspan="2">October measurements at sites</td></tr>
<tr><td>08/10/2012</td><td colspan="2" rowspan="4">October measurements at sites</td></tr>
<tr><td>15/10/2012</td></tr>
<tr><td>22/10/2012</td></tr>
<tr><td>29/10/2012</td></tr>
<tr><td>05/11/2012</td><td colspan="2">November measurements at sites</td></tr>
<tr><td>12/11/2012</td><td colspan="2" rowspan="3">November measurements on trials</td></tr>
<tr><td>19/11/2012</td></tr>
<tr><td>26/11/2012</td></tr>
<tr><td>03/12/2012</td><td colspan="2">December measurements at sites</td></tr>
<tr><td>10/12/2012</td><td colspan="2" rowspan="4">December measurements on trails</td></tr>
<tr><td>17/12/2012</td></tr>
<tr><td>24/12/2012</td></tr>
<tr><td>31/12/2012</td></tr>
<tr><td>07/01/2013</td><td colspan="2">January measurements at sites</td></tr>
<tr><td>14/01/2013</td><td colspan="2" rowspan="3">January measurements on trials</td></tr>
<tr><td>21/01/2013</td></tr>
<tr><td>28/01/2013</td></tr>
<tr><td>04/02/2013</td><td colspan="2" rowspan="3">Analysis and writeup. Final thesis</td></tr>
<tr><td>11/02/2013</td></tr>
<tr><td>18/02/2013</td></tr>
</table>

Establish trials to identify optimum return of agricultural products from applied nutrients (2.3)

Plots have been prepared for trials to identify optimum return of agricultural products from applied nutrients at Kabanyolo.

A Randomized Block Design will be used with 3 replicates of the 6 treatments A = No fertilizer, B-F = treatment with bioslurry at increasing rates. The block size for each replicate measures 6m x 2m, which is 12m². The individual treatment will be allocated per plot (2m x 2m) through a simple randomization procedure where pieces of paper each having a specific treatment (A-F), wrapped and put in a small box where they will randomly be selected and allocated to each plot; this provides an unbiased probability selection.

The blocks will laid along the gently sloping gradient to minimize site variation due to fertility gradient, pest and disease drift, soil erosion between blocks and also with in plots (Fig.12).

A	A	C	D	D	E
E	B	F	C	A	B
C	D	B	F	E	F

6m

12m

Figure 12. Example Randomised Block Design for Trial at Kabanyolo

Measurement of carbon and nutrients, energy and water use before establishment of biogas digesters (3.2) and in trials (3.3)

The nine farms selected to receive biogas digesters were interviewed using a questionnaire to find out how the farmers would like to use the bioslurry and which crops they would like to fertilise using the slurry. A copy of the responses given is attached in Appendix B.

An experimental design has been drawn up that incorporates the common agronomic practices identified through the questionnaire.

Type of crop - The survey determined that maize (Zea mays L) is a common seasonal crop for all the selected households. Other crops grown are bananas, pineapples, cabbages, sweet potato, passion fruit, tomatoes, ground nuts, coffee, yams, and pumpkins. Different farmers opted to apply slurry on different crops. However, to reduce the complexity of the trials and allow comparison between different households, the experiment was designed to apply bioslurry to maize in all cases.

Control - The common practice in Tiribogo is to fertilise maize during sowing using chicken manure (a mixture of chicken droppings and coffee husks). Two controls were included

1. Application of chicken manure at the normal rate,
2. Application of no fertilizer

This allows the trials to determine how well crops grow with bioslurry compared to normal management. Analysis of the chicken manure will be included to allow comparison of the performance of the crop following fertilization with bioslurry derived from the same quantity of manure as would have been used in normal practice.

Method of slurry application - The selected households apply chicken manure at sowing, "one cupful per dug hole". Manure is applied in each hole rather than being broadcast to avoid the growth of weeds and to reduce the amount manure used (most of farmers buy the chicken manure). The same volume and application method will be used for the bioslurry as is normal practice with chicken manure. This will provide a direct comparison of the fertilizer value by volume and follows an agronomic practice that farmers have found suits the conditions in Tiribogo.

Number of applications - The selected households apply manure once, during sowing. Ideally, this practice would also be followed with the bioslurry. However, the nutrients in bioslurry are in a highly available form, and so to avoid losses, it would be better to apply bioslurry on three occasions; during sowing, 20 and 55 days after sowing (Dosch & Gutser, 1996). Whether the farmers are happy with the extra labour required for repeated applications is still under investigation. If farmers are unhappy with the extra work needed, bioslurry will first be composted, and then applied as compost at sowing. Including composting would complicate the experimental design, and require a standardized protocol for composting to be established. So if acceptable to farmers, bioslurry will be applied directly.

Experimental design

For each of the nine farms, a Complete Randomized Block Design will be used, using 3 replicates of the 3 treatments A = No fertilizer, B = treatment with bioslurry, C = treatment with chicken manure. The block size for each replicate measures 6m x 2m, which is $12m^2$. The individual treatment will be allocated per plot (2m x 2m) through a simple randomization procedure where pieces of paper each having a specific treatment (A, B or C), wrapped and put in a small box where they will randomly be selected and allocated to each plot; this provides an unbiased probability selection. The blocks will position along the gently sloping gradient to minimize site variation due to fertility gradient, pest and disease drift, soil erosion between blocks and also with in plots (Figure 13).

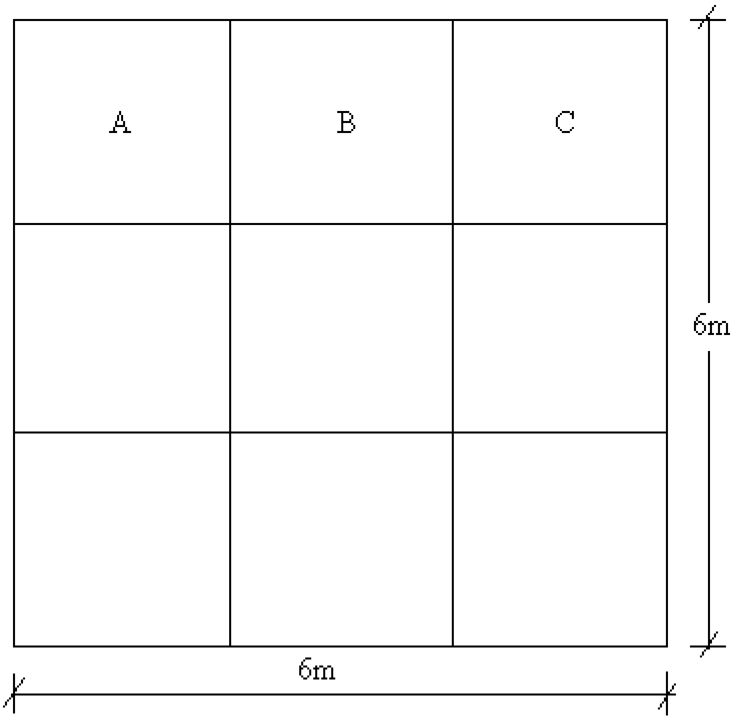

Figure 13. Complete Randomised Block Design for Trials at Tiribogo

Additional training - MSc3 has undergone additional training on the measurement methods available for use and the procedures followed at Makerere University. MSc3 is now ready to start making the baseline measurements for the established trials.

Expenditure

Expenditure to date for this component of the work is given below.

Table 8 – Expenditure for MSc3

ITEM	DESCRIPTION	QTY	UNIT PRICE (£)	AMOUNT (£)
Tuition payment	Year	2	1233	2,466
Cool boxes	No.	3	33	99
Flux chambers (5 litres)	No.	58	3	174
Sulphuric acid	2.5 litres	1	54	54
Boric acid	500gm	1	29	29
Acetic acid	2.5 litres	1	54	54
Conical flasks	250ml	25	2	50
Volumetric flasks	500ml	1	10	10
	1000ml	1	13	13
	2000ml	1	18	18
Syringe	20ml	20	0.3	6
	10ml	20	0.3	6
Syringe needles	Packets	2	1.3	2.6
Rubber tubing	Roll	2	20	40

ITEM	DESCRIPTION	QTY	UNIT PRICE (£)	AMOUNT (£)
Trowel		3	1.4	4.2
Filter papers (Whatman No. 1)	125mm	5	21	105
Centrifuge tubes(50ml)	50 /pck	5	17	85
Plastic sealing bags	Packets	6	4	24
Labour on preparation of experimental plots	No.	10	35	350
Transportation to project sites			171	171
UK Visa processing				78
TOTAL				**3,838**

RA1 - The potential impact of small scale biogas digesters on human health in Sub-Saharan Africa through changes in pathogen exposure and household air quality

General description and revised work plan

The work will determine

- baseline levels of exposure to both airborne pollution and microbiological contamination in rural homes in Uganda
- the changes in human exposure to airborne pollutants and how they are likely to impact on respiratory health
- the changes in human/environment exposure to microbiological and pathogenic organisms and how they are likely to impact on diarrhoeal disease and microbial contamination of the environment.

The detailed work plan has been revised due to delays both in the installation of biogas digesters and in sourcing equipment for pathogen measurements. However, baseline air sampling before installation of biogas digesters has been completed. Real-time data on fine particulate matter (PM2.5) and CO levels was measured over a 24h period with exposure metrics of time-weighted average, peak exposure and percentage of time when household air concentrations exceed threshold levels expressed. Measurements were done using a TSI AM510 Sidepak Personal Aerosol Monitor and Lascar CO logger, allowing air concentrations of indoor air pollutants to be measured at 1 minute intervals over a 24h period.

The laboratory for pathogen measurements is now fully equipped, and baseline measurements of the distribution of pathogens in the vicinity of the farm will start shortly. The pathogen content of digested slurries will be measured at different rates of throughput. Monitoring of indicator organisms will be used to estimate the survival of pathogens originating from animal or human waste. For plant wastes, survival of key plant diseases in the digested slurry will be monitored. Total aerobic mesophilic bacterial and fungal counts will be determined using standard microbiological protocols (Standard Committee of Analysts, 2007). Faecal enterococci, Esherichia coli counts, and faecal and total coliform counts will be obtained by membrane filtration (Standard Committee of Analysts, 2002a,b; 2003; 2009; 2010a). Sulphite reducing Clostridia (spores and cells) will be measured by membrane filtration and anaerobic culture (Standard Committee of Analysts, 2010b). Likely die-off of enteric viruses during the anaerobic decomposition process will be quantified using non-pathogenic bacterial coliphage f2 in digester input and output samples, enumerated by plaque assay using the plate overlay method on lawns of E. coli K12 (Traub et al., 1986). Any occupational diseases that farmers contract during the pilot projects will be documented and a qualitative risk assessment carried out, allowing guidelines for safe handling of wastes to be determined.

Information about potential changes in indoor air quality and pathogen exposure with installation of a biogas digester will be included in an accessible way on the information boards and will contribute to the information pack provided with the digesters.

Table 9 – Revised work plan for RA1

Date	Task	
05/03/2012 12/03/2012 19/03/2012 26/03/2012 02/04/2012 09/04/2012 16/04/2012 23/04/2012	Training in microbial techniques at JHI	Questionnaire design Ethics application Equipment and reagents ordering Visa Excel risk assessment training Risk assessment and insurance
30/04/2012 07/05/2012 14/05/2012	Arrange delivery of consumables and equipment	

Date	Task		
21/05/2012			
28/05/2012			
04/06/2012	First visit and consent	Dry run micro.sampling	Dry run air sampling
11/06/2012	Visit A - sites 1-2		
18/06/2012	- sites 3-4		
25/06/2012	- sites 5-6		Air sampling
02/07/2012	- sites 7-8		
09/07/2012	- site 9		
16/07/2012	Holiday		
23/07/2012			
30/07/2012			
06/08/2012	Establish microbiology laboratory for biogas digester work		
13/08/2012			
20/08/2012	Visit A - sites 1-5	Micro.sampling	
27/08/2012	- sites 6-9	- before installed	
03/09/2012	- sites 10-14	Micro.sampling	
10/09/2012	- sites 15-18	- no installation	
17/09/2012	Visit B - sites 1-5	Micro.sampling	Air sampling (2 homes / week)
24/09/2012	- sites 6-9	- after installed	
01/10/2012	- sites 10-14	Micro.sampling	
08/10/2012	Ugandan public holiday		
15/10/2012	- sites 15-18	- no installation	Air sampling (2 homes / week)
22/10/2012			
29/10/2012	Complete training of MSc2 in microbial and air quality measurement techniques		
05/11/2012			
12/11/2012			
19/11/2012			
26/11/2012			
03/12/2012	Write-up papers and report		
10/12/2012			
17/12/2012			
24/12/2012			
31/12/2012			
07/01/2013			
14/01/2013			
21/01/2013			
28/01/2013			
04/02/2013			
11/02/2013			
18/02/2013			

Measurement of pathogens and household air quality before establishment of digesters (3.7)

Purchase of equipment

A summary of planned and actual equipment and consumables purchases for this part of the project is given in table 10. There is an expected underspend of £6046, which will be used to pay for travel of staff to Uganda to provide additional contributions to different aspects of the project.

Table 10 – Summary of planned and actual equipment / consumable purchases for measurement of pathogens and household air quality

Item	Cost
- Equipment for measureing household air quality	
TSI Sidepacks x 2	£4,229
CO/Lascar monitors x 2	£123
AA Battery packs x 2	£440
Subtotal	£4,792
- Equipment for pathogen measurements	
2 x incubators	£6,000
1 x microscopes	£3,000
2 x anaerobic jars	£680
Water bath	£600
Subtotal	£10,280
Associated consumables 500 x gas generating sachets	£815
10 x anaerobic indicators (quality control)	£268
Gas generation catalyst	£257
Membrane filters x 20 boxes	£1,200
Indicator culture media & consumables (MacConkey,Nutrient,Eosine blueagars,petri dishes etc)	£4,000
Specific pathogen culture - selective agars & recovery broths; biochemical confirmation tests	£2,000
Membrane filtration manifold	£200
Subtotal	£8,740
Total planned	£23,812
Total already purchased	£14,570
Still to purchase	£3,196
Total expected expenditure	£17,766
Balance	£6,046

Measurement of household air quality

Household air quality was monitored in the nine homes that have been selected to receive the installation of a biogas digester in the village of Tiribogo. Household air quality was assessed by measuring the airborne concentration of two primary pollutants: particulate matter less than 2.5μm in diameter ($PM_{2.5}$); and carbon monoxide (CO). These metrics were chosen as they are commonly used to determine both outdoor and indoor air quality by national and international health protection agencies (e.g. WHO and US EPA).

Monitoring took place within the room space in the household where the majority of cooking was reported to take place and was carried out over a 24 hour period. Concentrations of both pollutants were logged every minute using a TSi SidePak AM510 (for $PM_{2.5}$) and a Lascar EL-USB-CO for CO. The collected data was downloaded, 24 hour averages calculated and peak concentrations found. The $PM_{2.5}$ concentrations collected by the SidePak were corrected by a factor 0.295 to account for the difference in density of the aerosol used to calibrate the SidePak (Arizona road dust) and that created by the combustion process of organic matter.

Typical $PM_{2.5}$ and CO concentrations for a 24 hour period are shown below:

Table 11 – The 24 hour average PM2.5 and CO concentrations found in the homes at Tiribogo

Home ID	24h average (SD) $PM_{2.5}$ Conc μgm^{-3}	Peak $PM_{2.5}$ Conc μgm^{-3}	24h average (SD) CO Conc ppm	Peak Pre Installation CO Conc ppm
1	828 (1520)	5900*	10 (17)	214
2	187 (600)	5900*	5 (13)	224
3	722 (1500)	5900*	10 (13)	106
4	21 (57)	1560	3 (13)	340
5	180 (428)	4460	4 (7)	84
6	1160 (1920)	5900*	31 (46)	272
7	83 (222)	2324	2 (5)	52
8	211 (531)	5040	7 (16)	226
9	350 (504)	4600	6 (5)	26
Arithmetic Mean	416		9	171.3
Geometric mean	244		6	

*indicates that the maximum concentration of the SidePak was attained and likely exceeded

The mean 24 hour $PM_{2.5}$ concentrations found in the homes at Tiribogo ranged from 21.1 to 1160 $\mu g\ m^{-3}$ (the arithmetic mean for the individual homes can be seen in table 11). Eight homes exceeded the WHO 24 hour guidance concentration of 25 $\mu g\ m^{-3}$. Home 4 is the only home where the $PM_{2.5}$ concentration was found to be less than the WHO 24 hour guidance. The $PM_{2.5}$ concentration found for homes 1, 2, 3 and 6 are likely to be conservative as the concentrations logged exceeded the maximum concentration that can be measured by the SidePak. The geometric mean concentration of all the 9 homes was found to be 243.5μgm^{-3} almost ten times the guidance value recommended by the WHO

The CO levels found ranged from 1.5 to 30.6 ppm (see table 11 for the 24 hour average concentration for each of the homes monitored). Four homes were found to be above the recommended 6.1 ppm (24 hour average) recommended by the WHO of which three are above the maximum 8 hour average concentration of 8.73 ppm. One home was found to be above the 1 hour maximum concentration set out by the WHO (home 6). The geometric mean CO concentration of all the homes is equal to the maximum 24 hour average concentration set out by the WHO.

The concentrations of CO and $PM_{2.5}$ follow each other closely; where one peaks the other peaks. This occurs for all homes monitored in this current study. An illustrative example is show in Fig. 14 below. In this case there is a period of high concentrations in the morning through to the early afternoon likely corresponding to cooking breakfast/lunch and in the early evening a series of peaks occur likely corresponding to the evening meal being cooked. It should be noted that a lot of the meals being eaten are stewed and are likely to be cooked over a long period of time accounting for the high concentrations of $PM_{2.5}$ and CO over several hours.

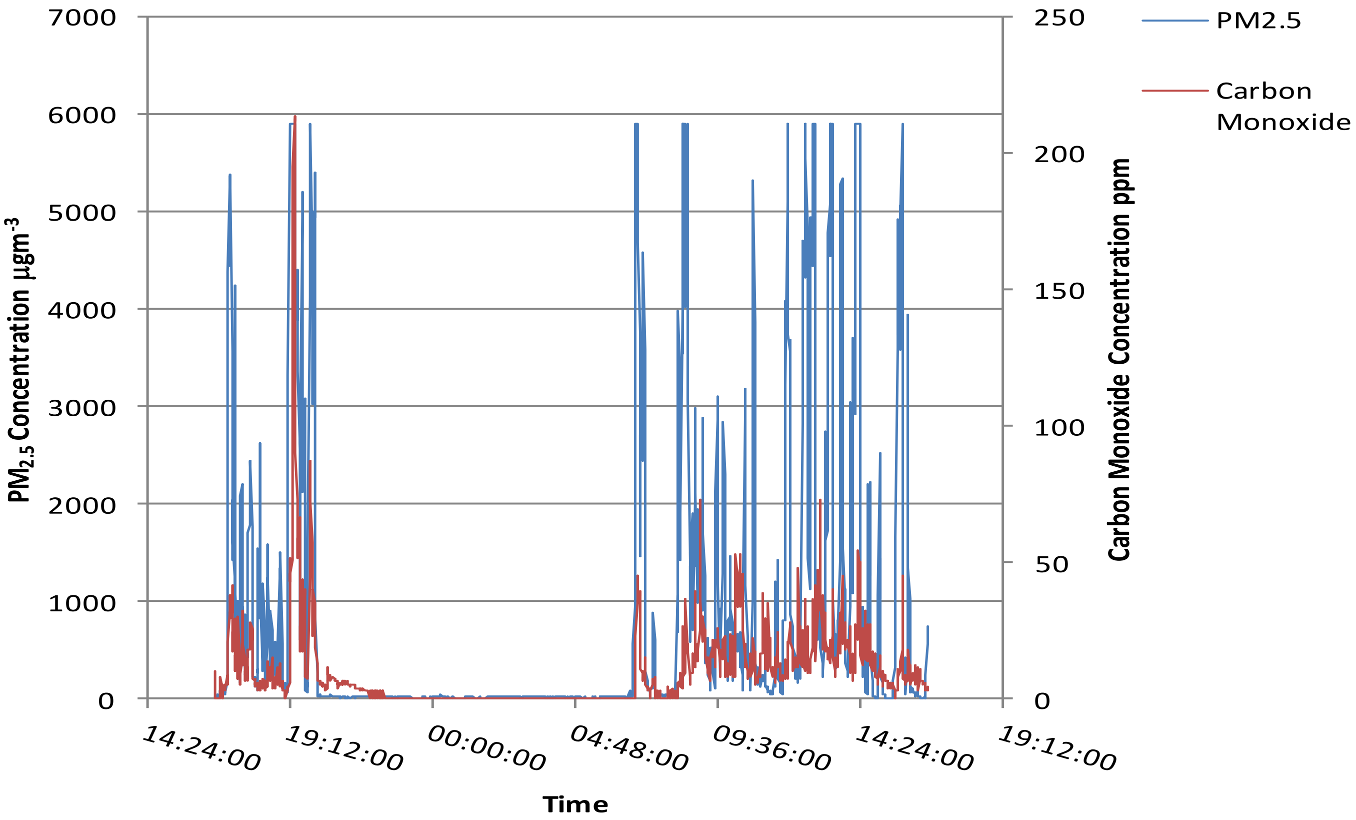

Figure 14 - Typical $PM_{2.5}$ and CO concentrations in a 24 hour period from a home at Tiribogo

Home 7, one of the homes with the least $PM_{2.5}$ and CO concentrations, had a different cooking area layout when compared to the majority of the homes monitored. This is illustrated in Fig. 15 below (Home 7 is on the left and a typical cooking area is shown on the right). The cooking area of home 7 was in an open area with only a roof and no walls enclosing it. The cooking facilities at the other homes were in enclosed buildings. This is likely to account for the lower $PM_{2.5}$ and CO concentrations found for this home.

Figure 15 - Difference between the cooking area of Home 7 and the other homes. (Home 7 is on the left)

Measurement of pathogen distribution

The delivery of equipment and associated items for this part of the work has been logistically difficult with many delays. However, as of the 15th August 2012 all the items required for carrying out the pathogen distributions have now been received in the laboratory. The laboratory facilities are now in place and work on sample collection and analysis will commence shortly.

Work still to be undertaken

Air monitoring

The nine homes in which air quality has previously been monitored pre-installation will be monitored again after the biogas digester installation has been completed and householders have begun to cook with the gas supplied. Air sampling will occur at rate of two households per week.

Pathogen distribution work

Due to equipment delivery delays, the pathogen distribution work has been amended. Eighteen homes will now be monitored for pathogen distribution pre and post installation of the biogas digesters. Nine of these homes will have biogas digesters installed and the nine other homes will be used as controls i.e. will have no biogas digester.

Prior to be the biogas digesters being installed the following tests will be carried out (see table 12 and table 13): pre-installation swab samples will be taken from plates or cooking utensils and also of door handles indicating what is being transferred by the people of the home; boot swab samples will be taken in the home; samples from the area surrounding the home; and also of the area around manure collecting area. Post-installation samples will include those carried out pre installation with the addition of samples taken from the digestate and the digester feed stock. Each of the pathogen samples (swab, boot swab, feedstock and digestate samples) will be tested for the following organisms E.coli and colliforms. The digestate and feedstock samples will also be tested for the organism, clostridia. The samples collected during this phase will be retained for additional molecular analysis should further funding become available in the future.

Table 12 - Pre Biogas Digester installation pathogen distribution testing

Home type	No.	Number of swab samples per home	Sample item	Number of boot swabs per home	Boot sample location
Digester to be installed	9	2	1) Multiple plates or utensils 2) Door handle	3	1) Around outside of house 2) Inside house 3) Near manure area
No digester to be installed	9	2	1) Multiple plates or utensils 2) Door handle	3	1) Around outside of house 2) Inside house 3) Near manure area if there is one

Table 13 - Post biogas digester installation pathogen distribution testing

Home type	No.	Number of swab samples per home	Sample item	Boot swabs per home	Boot sample location	Digestate	Digester feedstock
Digester to be installed	9	2	1) Multiple plates or utensils 2) Door handles	3	1) Around outside of house 2) Inside house 3) Near manure area	Y	Y
No digester to be installed	9	2	1) Multiple plates or utensils 2) Door handles	3	1) Around outside of house 2) Inside house 3) Near manure area if there is one	N	N

Makerere University staff will be trained on the techniques used to determine the pathogen distribution and this will be undertaken during this phase of the project.

Communication Plan and User Engagement

Based on the experiences of several of the Ugandan project team members and discussions at the project kick off meeting, it was decided that the most effective approach (in terms of time and budget availability) in the development of training and communication materials for use by community-based champions, was to produce draft information sheets containing the key messages and to then provide community members in Tiribogo with the opportunity to comment and adapt these to their needs through a series of participatory sessions with various group members.

To this end, a series of information sheets were developed in consultation with a graphic designer with previous experience of working on similar biogas initiatives in Uganda (see Appendix B). These were developed to be primarily visual, as a tool to help facilitate future community-to-community engagement sessions to enable expansion in the uptake of the balloon digester technology. Developed initially in English, these information sheets will be translated into the local Bantu language, Luganda.

The draft sheets were taken by Ugandan project partner GHU to a meeting in Tiribogo on 27th July and community members were given the opportunity to comment on these. Feedback was collated and the relevant revisions were incorporated into a second draft.

The training and communication material will be made available in a number of formats including, printed A4 booklets, A0 laminated sheets for use in community workshop settings and as printed sheets for use in local schools. Digital copies will also be placed on the dedicated project website that has been created http://www.abdn.ac.uk/sustainable-international-development/research/networks/digesters-p/

The project website will be further developed over the coming months to incorporate research results from the various workpackages.

In addition to the communication materials being prepared, the project is also exploring other routes for dissemination. This includes an article to be submitted to PLA Notes at the end of August for publication in December 2012.

The MSc students and RA1 all intend to submit papers to the "Micro Perspectives for Decentralized Energy Supply" 2nd International Conference, to be held 27th February to 1st March, 2013, in Berlin, Germany. This meeting coincides with the completion of this project, and so will provide an ideal opportunity for the work to be publicised to the wider European scientific community.

Conclusions

The timing of work planned in the second quarter of the project has been changed by delays in delivery of equipment; biogas digesters and laboratory equipment for pathogen studies. However, the work schedule has been reorganised to accommodate these delays, and the problems this introduced to the wrk schedule have been overcome by completing other tasks earlier in the project. One biogas digester has been successfully installed at the MU experimental station at Kabanyolo, and work is progressing as planned with the field trials at that site. Trials in Tiribogo have been planned, and will get underway as soon as the remaining nine biogas digesters have been delivered and installed.

Acknowledgements

We are grateful to DFID for providing funding for this research.

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Appendix A – Project work plan

	Organisations
GHU	Green Heat Uganda
JHI	James Hutton Institute
MU	Makerere University
ORS	Orskov
UoA	University of Aberdeen

	MSc students
MSc1	MSc registered at MU with JM & PW - input from KG & BB = Moris Kabyanga
MSc2	MSc registered at UoA with JS - input from GD, BO & KB = Vianney Tumwesige
MSc3	MSc registered at MU with ES, JBT & CN - input from EB, NM, JS, RM & MS = Swaib Semiyaga
RA1	RA registered at UoA with SS & NS - input from ES, KY & LA = Andrew Apsley

Personnel

AA	Andrew	Apsley	BO	Bob	Orskov
LA	Lisa	Avery	ES	Elly	Sabiiti
BB	Bedru	Balana	SS	Sean	Semple
EB	Liz	Baggs	JS	Jo	Smith
KB	Karsten	Bechtel	NS	Norval	Strachan
GD	Grant	Davidson	MS	Madhu	Subedi
KG	Klaus	Glenk	JBT	John Baptist	Tumuhairwe
RM	Robin	Matthews	VT	Vianney	Tumwesige
NM	Nick	Morley	PW	Peter	Walekhwa
JM	Johnny	Mugisha	KY	Kenneth	Yongabi
CN	Charles	Niwagaba			

	Milestone	Start date	Delivery date	Organisation responsible	Main person doing work	Additional input
1	**What is the potential of flexible-balloon digesters in SSA?**					
1.1	Sociological and economic research to identify villages in regions where implementation of flexible-balloon digesters will be piloted	01/03/2012	31/05/2012	MU	MSc1	JM, PW, BB, KG
1.2	Socioeconomic analysis, exploring cost/benefits and willingness to pay	01/06/2012	19/02/2012	MU	MSc1	JM, PW, BB, KG
2	**What changes are needed in design of equipment and farming systems?**					
2.1	Installation of flexible-balloon digesters at 10 selected sites	01/06/2012	30/06/2012	GHU	VT	
2.2	Provide training to local people on installation of flexible-balloon biogas digesters	01/06/2012	30/06/2012	GHU	VT	GD
2.3	Document engineering problems associated with technical implementation	01/06/2012	30/06/2012	MU	MSc2	KB, GD, MSc3, RA1
2.4	Establish trials to identify optimum return of agricultural products from applied nutrients	01/07/2012	31/07/2012	UoA	MSc2	MSc3,RA1
2.5	Comprehensive time-management analysis to determine potential labour savings and improved designs of cooking equipment and farm layout	01/08/2012	30/09/2012	JHI	MSc2	GD, JS, KB
2.6	Integrate results from measurements in (3) into systems model	01/10/2012	31/12/2012	UoA	MSc2	JS
2.7	Provide an estimate of the potential regional improvement in water quality, crop production and carbon sequestration	01/01/2013	31/01/2013	UoA	MSc2	JS
2.8	Identify regions where digesters are likely to be most beneficial to the rural community.	01/02/2013	20/02/2013	UoA	MSc2	JS
3	**What is the value of a biogas digester?**					
3.1	Training in measurement techniques for measurement of carbon, nutrients, energy and water flows	01/03/2012	31/05/2012	UoA (1,2) / MU (3)	MSc3	NM, EB, ES, JBT
3.2	Measurement of carbon, nutrients, energy and water flows before installation	01/05/2012	31/05/2012	MU	MSc3	JBT, ES, NM, EB
3.3	Measurement of carbon, nutrients, energy and water flows in trials	01/06/2012	31/07/2012	MU	MSc3	JBT, ES, NM, EB
3.4	Measurement of carbon, nutrients, energy and water flows after installation	01/06/2012	20/02/2013	MU	MSc3	JBT, ES, NM, EB
3.5	Training in measurement techniques for measurement of pathogen distribution and household air quality	01/03/2012	31/05/2012	UoA & JHI (1,2) / MU (3)	RA1	NS, LA, SS, ES, JBT, KY
3.6	Measurement of pathogen distribution and household air quality before installation	01/05/2012	31/05/2012	UoA	RA1	NS, LA, SS, ES, JBT, KY
3.7	Measurement of pathogen distribution and household air quality in trials	01/06/2012	31/07/2012	UoA	RA1	NS, LA, SS, ES, JBT, KY
3.8	Measurement of pathogen distribution and household air quality after installation	01/06/2012	20/02/2013	UoA	RA1	NS, LA, SS, ES, JBT, KY
3.9	Documentation of diseases contracted	01/01/2013	20/02/2013	JHI	RA1	NS, LA, SS, ES, JBT, KY
3.10	Presentation of results on information boards	01/01/2013	20/02/2013	JHI	MSc3, RA1	GD
4	**User Engagement**					
4.1	Identify social and economic barriers to uptake	01/03/2012	31/05/2012	MU	MSc1	GD, JM, PW, BB, KG
4.2	Try out approaches to overcome barriers	01/06/2012	30/06/2012	JHI	MSc1	GD
4.3	Address engineering problems associated with technical implementation	01/06/2012	30/06/2012	JHI	MSc2	GD
4.4	Present results of research to local people and downstream users in an accessible way	01/01/2013	20/02/2013	JHI	GD	MSc1, MSc2, MSc3, MSc4

Date	MSc1	MSc2	MSc3	RA1	Notes
05/03/2012	Literature survey; Household selection for socio-economic survey	Source digesters & literature review; Design baseline survey with MSc1, MSc2 and RA1; Documentation of engineering problems and time management analysis	Prepare for trip to UoA; Design baseline survey with MSc1, MSc2 and RA1	Training in microbial techniques at JHI; Questionnaire design Ethics application Equipment and reagents ordering Visa Excel risk assessment training Risk assessment and insurance	
12/03/2012			Training at the UoA		
19/03/2012					
26/03/2012	Design of questionnaire for the socio-economic baseline survey	Selection of farmers			
02/04/2012					
09/04/2012					
16/04/2012					
23/04/2012					
30/04/2012			Exams and further training at MU		
07/05/2012				Arrange delivery of consumables and equipment	
14/05/2012					
21/05/2012					
28/05/2012					
04/06/2012	Field survey; Questionnaire pre-testing Baseline survey		Interview farmers at selected sites to find out how they want to use bioslurry	First visit and consent; Dry run micro.sampling; Dry run air sampling	
11/06/2012				Visit A - sites 1-2; Air sampling	
18/06/2012		Installation of digester at Kabanyolo		- sites 3-4	
25/06/2012		Collect together data and information for use in systems modelling; Setup trials at Kabanyolo with MSc3	Decide on experimental design	- sites 5-6	
02/07/2012				- sites 7-8	
09/07/2012				- sites 9-10	
16/07/2012				Holiday	
23/07/2012					
30/07/2012			Baseline measures at sites before sowing		
06/08/2012	Cost items identified and quantified; Benefit items identified and approaches to quantification outlined; Description of the study area (farming systems, perception,...) via talking to people, visits, secondary data	Setup trials with MSc3; Training in microbial and household air quality techniques	Setup trials with MSc2; Baseline measures for trials at MU experimental site	Setup lab	
13/08/2012					Manual complete
20/08/2012		Installation of biogas digesters at selected sites; Training of farmers in installation, maintenance and value of digesters		Visit A - sites 1-5 Micro.sampling - before digester installed	Quarterly report due; Installation starts
27/08/2012				- sites 6-9	
03/09/2012			September measurements at sites	- sites 10-14 Micro.sampling	
10/09/2012			September measurements on trails	- sites 15-18 - no installation	
17/09/2012				Visit B - sites 1-5 Micro.sampling - after digester installed; Air sampling (2 homes / week)	Visit Lisa, Kenneth & Jo (?)
24/09/2012				- sites 6-9	Installation complete'
01/10/2012	Entry and analysis of baseline data, completion of report on baseline survey and preparation of data collection tools for follow-up survey	Setup trials at Tiribogo with MSc3	October measurements at sites	- sites 10-14 Micro.sampling	
08/10/2012			October measurements at sites	Ugandan public holiday	
15/10/2012				- sites 15-18 - no installation; Air sampling (2 homes / week)	
22/10/2012					
29/10/2012		Visit C - sites 1-5 Micro.sampling - after installation - sites 6-9 - sites 10-14 Micro.sampling - sites 15-18 - no installation; Air sampling (2 homes / week)		Complete training of MSc2 in microbial and air quality measurement	
05/11/2012			November measurements at sites	Write-up papers and report	
12/11/2012			November measurements on trials		
19/11/2012					
26/11/2012		Data analysis			
03/12/2012	Second round survey		December measurements at sites		
10/12/2012			December measurements on trails		
17/12/2012					
24/12/2012		Debrief and clean-up			
31/12/2012		Prepare for trip to Aberdeen			
07/01/2013	Analysis and write-up	Training and application of systems analysis at UoA.; Analysis and write-up; Final thesis	January measurements at sites		
14/01/2013			January measurements on trials		
21/01/2013					
28/01/2013					
04/02/2013	Final thesis		Analysis and writeup. Final thesis		
11/02/2013					
18/02/2013					

Appendix B – Responses on how to use bioslurry

Note: Presented are the responses from interviewed farmers who were selected to receive biogas digesters. Chicken Manure means chicken droppings mixed with coffee husks which are used as a bedding layer for poultry.

Code	Crops grown	Fertilizers currently used	Crops currently fertilized	How Fertilizers are currently used	Crops desired to be fertilized with slurry	How to use the slurry	Any comment
H21	Banana Maize Beans Sweet potato	Chicken manure Crop wastes	Maize Banana Beans	Maize – Manure applied on a plant shoot. Banana – Garden covered with crop waste ~ mainly from maize stalks.	Maize	I think applying it directly may burn the crops. It needs to first be stored for about 2 weeks and then applied to the garden before planting.	We keep more than 800 heads of chicken. This can produce enough manure that we need in gardens.
H17	Banana Maize G. Nuts Beans Cabbages Yams Sweet potato Coffee	Chicken manure Animal dung (composited)	Maize Beans Cabbages	Maize – A hole is dug + manure + seed + soil cover. Beans + Cabbages – Plant shoot surrounded by manure.	Cabbages	I would need to compost it first, and then apply it in the entire garden before planting.	Chicken manure we use is bought. We have a few chickens which are reared in a free range system.
H47	Tomatoes Banana Greens Maize cabbages	Chicken manure UREA and NPK SUPERGROW	Tomatoes Banana Greens Maize	Maize first planted, fertilizer applied when the shoot comes out. NPK – Spread in the entire garden before planting SUPERGROW – Spraying on the leafy vegetables	Tomatoes Green paper Maize Cabbages Greens	Stored for some time and then sprayed to crops.	Chemical fertilizers are usually applied on Greens (Nakatti) and Cabbages. For Tomatoes and Maize – Chicken manure is used. Chicken manure is bought from

				UREA- Mixed with water and sprayed on the crops			Kampala at 2000 – 3000/= per bag before transportation.
H27	Banana Maize Pumpkins Beans	Chicken manure Animal dung	Maize Banana Pumpkins	Maize – A hole is dug + manure + seed + soil cover. Banana – A hole is dug aside of plant ~ 100cm + Manure + soil cover. Cow dung is used when dry.	1. Maize 2. Banana 3. Pumpkins	Need to be trained. Its something new and I have never used it.	Chicken manure is bought from Kampala at ~ 7000/= per bag (transport inclusive)
H1	Banana Maize Cassava Beans Sweet potato Coffee	Chicken manure Animal dung Crop wastes	Maize Banana Coffee	Maize – A hole is dug + manure + seed + soil cover. Banana – A hole is dug + Manure + plant shoot + soil.	1. Maize 2. Banana 3. Coffee	Need to be trained in different possible ways. I would like to apply it per hole dug to avoid over growth of weeds.	We can produce the required fertilizers locally.
H24	Banana Maize Beans Cassava Sweet potato Irish potato	Chicken manure Crop wastes	Maize Banana	Maize – Dig a hole + maize seed + soil cover. When the shoot comes out, it is surrounded by manure. Crop wastes – remains like maize stalks are laid in Banana gardens.	Maize	When its from the digester, we need to leave it for a few days and then applied to crops.	
H13	Maize	Chicken manure	Maize	Maize – Dig a hole +	Maize	Store it for some	Animal dung is

	Banana Beans Sweet potato Yams	Animal dung	Banana	Manure + seed + soil cover	Banana	time and then spraying the entire area before planting.	rarely used on a large scale due to its scarcity and cannot be bought unlike chicken manure. Chicken manure is bought at 3500 to 4000/= per bag
H11	Maize Banana Sweet potato Vegetables	Chicken manure	Maize Banana Sweet potato Vegetables	Maize – Dig a hole + seed + soil cover + manure on top Banana – Put in a hole before planting. For the grown plants, manure is laid in trenches dug parallel to planted rows. Sweet potato – Manure spread over the entire area. Vegetables – Manure spread over the garden and seeds are added.	Vegetables Banana	Spreading it in the trenches for fertilizing Banana	Chicken Manure costs 2500 to 3000/= per bag before transportation.
H20	Maize Banana Beans Sweet potato Jackfruit Passion fruit G. Nuts Pumpkin Tomatoes	Chicken manure	Maize Banana Vegetatables	Maize – Dig a hole + Manure + seed + soil cover. Banana – Manure is spread around the plant. Vegetable – Coffee husks + seed + Manure.	Maize Banana	That's the information to be provided by the researchers.	Animal dung is dispersed in different locations; we need to know when installation is to begin so that we can start to pile it up. We keep poultry so we don't buy Manure.

Appendix C – Biogas information sheets

How Biogas Works

Biogas is a gas that is produced from the decomposition of organic waste such as animal waste, human waste and dead plants. There are many benefits to using biogas fuel, which make it a lot better to use than traditional charcoal and wood fuel cooking stoves.
Biogas can also be used for lighting and electricity generation

Wet dead plants and human and animal waste are fed into the biogas digester, where they are broken down into a gas.

This gas is piped through to a connecting stove where it can be used as a clean, safe and quick cooking fuel.

Leftover waste from the digester can be used as a natural and efficient fertiliser for crops and plants or in aquaculture.

Benefits of Biogas:

Quick
Biogas can be turned on instantly. You do not need to spend time collecting firewood and making a fire.

Healthy
Smoke from charcoal and wood stoves is harmful. Biogas produces very little smoke.

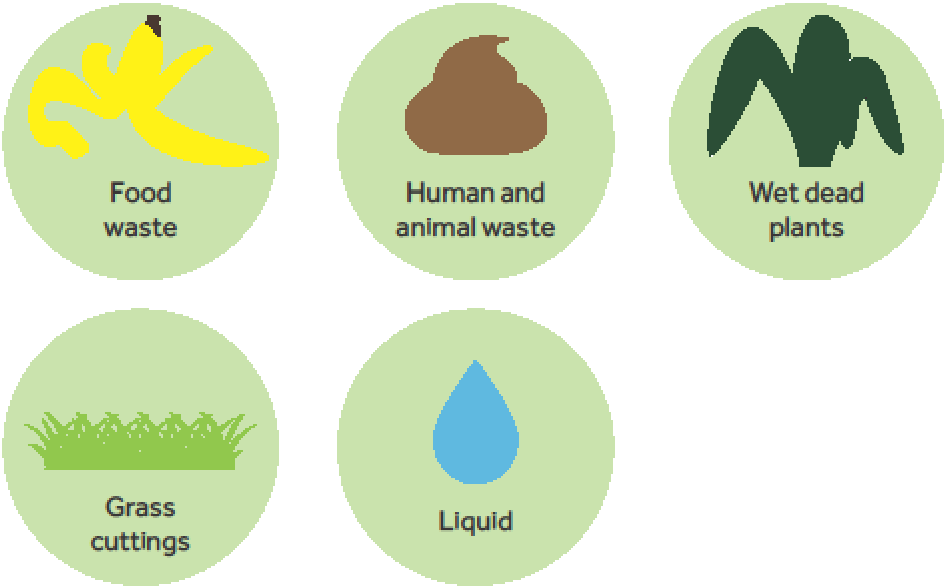
Environmentally Friendly
With biogas there is no need to cut down trees for firewood.

Cheap
You do not need to buy charcoal or firewood to cook with biogas.
All you need is human/animal waste, dead plants and water.

Fertiliser

What Can Be Put In It

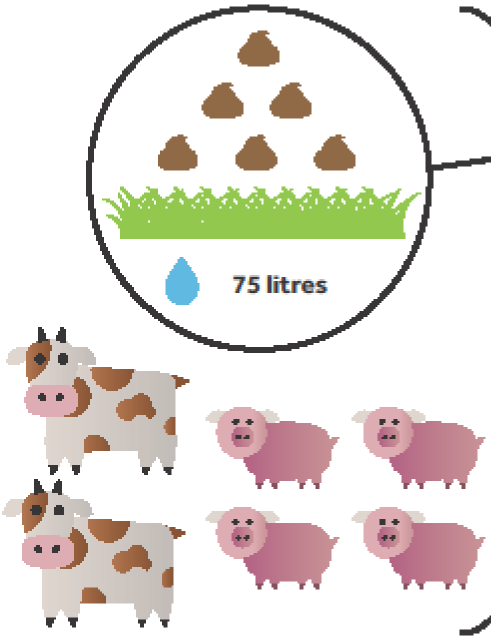
For biogas to work properly it is important to feed it correctly. Organic waste and water should be fed into the digester daily. Never put waste such as plastic and glass into the digester.

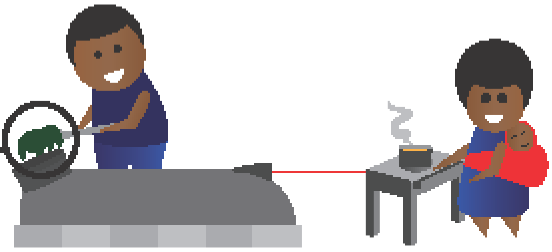


What Must Not Be Put In It

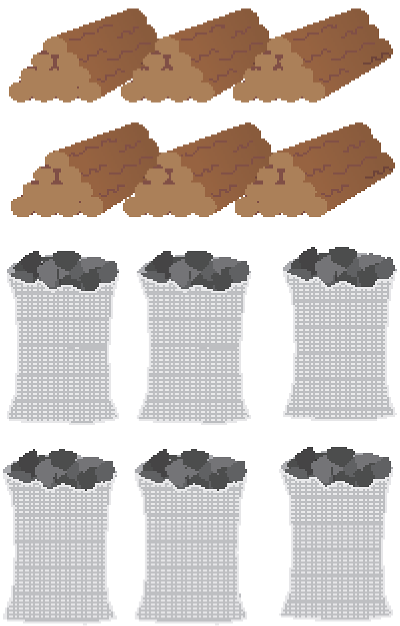
How To Look After It

Biogas works at its best when it is looked after properly. For it to be at its most efficient follow these guidelines.





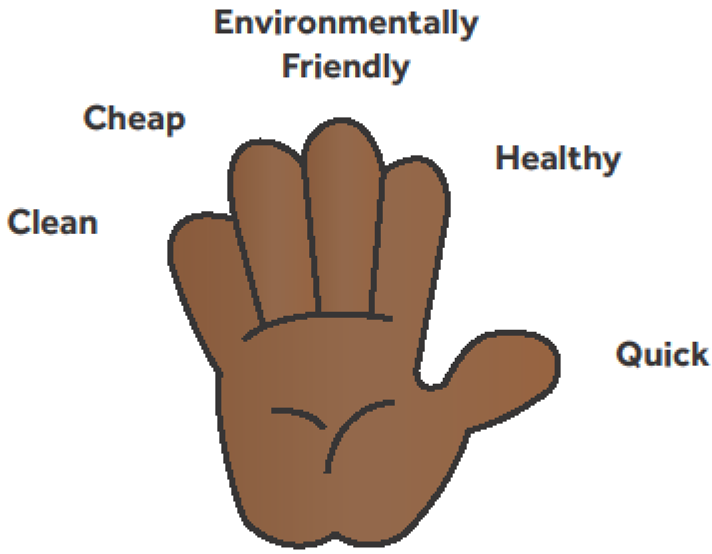
For 3 - 5 hours of cooking fuel a day, a biogas digester requires the animal waste from either 2 cows or 4- 8 pigs, dead plants, leftover food waste and 75 litres of water.

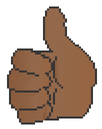


For 3 - 5 hours of cooking fuel a day, a traditional cook stove uses lots of wood and charcoal. This can be very expensive and time consuming. The smoke that these cook stoves produce can also be very harmful.

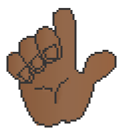
Benefits of Biogas

There are 5 main benefits to using biogas over traditional cooking methods.

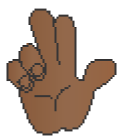




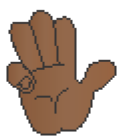
Quick
Biogas can be turned on instantly. You do not need to spend time collecting firewood and making a fire.



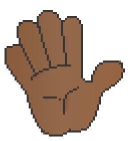
Healthy
Smoke from charcoal and wood stoves is harmful. Biogas produces very little smoke.



Environmentally Friendly
With biogas there is no need to cut down trees for firewood.



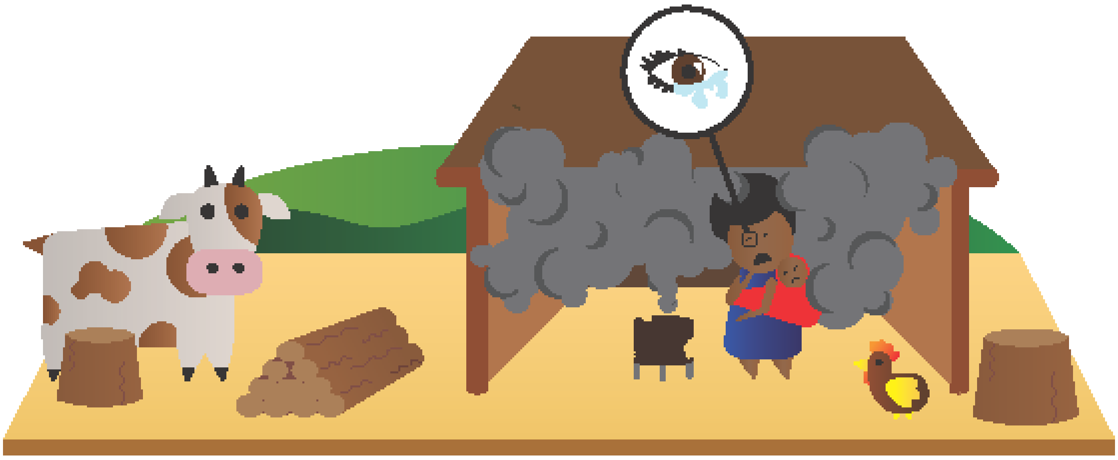
Cheap
You do not need to buy charcoal or firewood to cook with biogas.
All you need is human/animal waste, dead plants and water.
Fertiliser



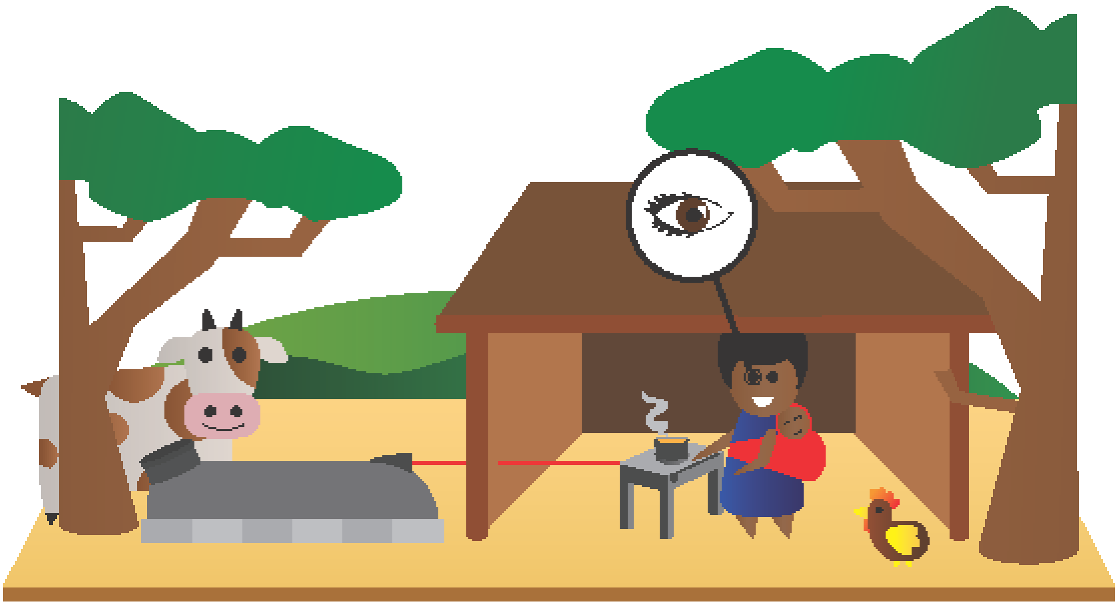
Clean
Helps to clean up animal and human waste to prevent spread of diseases

Benefits - Healthy

Cooking with biogas produces a lot less air pollution inside your home. This dramatically reduces the risk of many health problems such as coughs, eye problems, pneumonia, heart problems and even death.



Cooking with a charcoal/wood stove



Cooking with a biogas stove

Benefits - Fertiliser

The slurry left over from the biogas digester can be used as a good fertiliser for crops and plants. This will help to improve agricultural productivity.

Cooking with a charcoal/wood stove

Cooking with a biogas stove

Benefits - Clean

Cooking with biogas improves sanitation because human and animal waste can be placed into the digester to produce cooking gas. This helps to create a cleaner environment and reduce the risk of spreading germs and diseases.

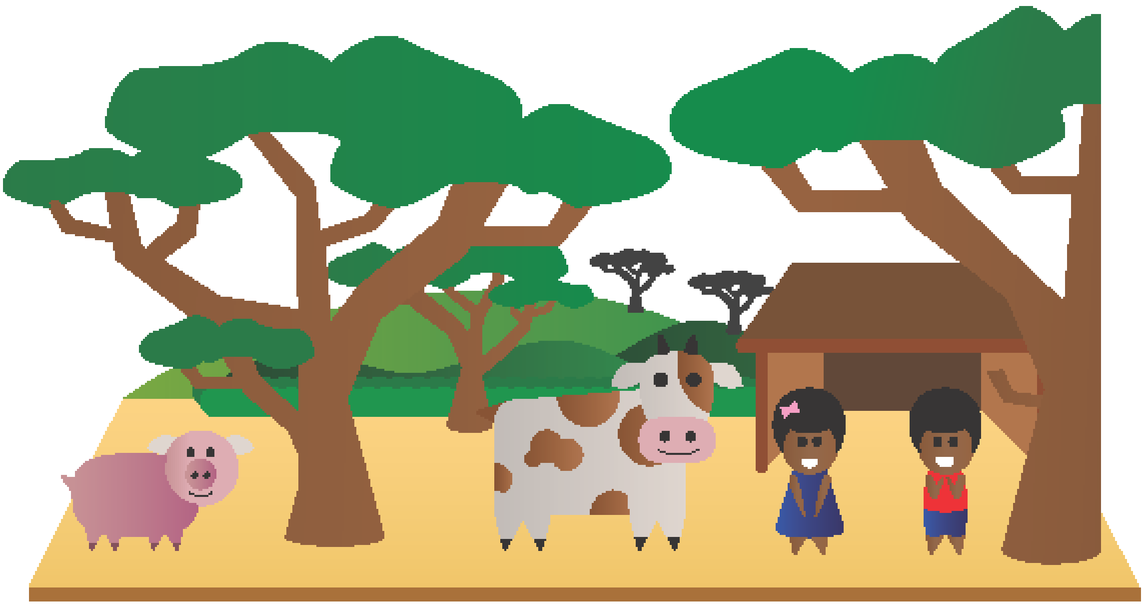
Cooking with a charcoal/wood stove

Cooking with a biogas stove

Benefits - Environmentally Friendly

Cooking with biogas means that less fuel needs to be collected. This means that trees do not need to be cut down. which helps to promote a natural and sustainable environment.

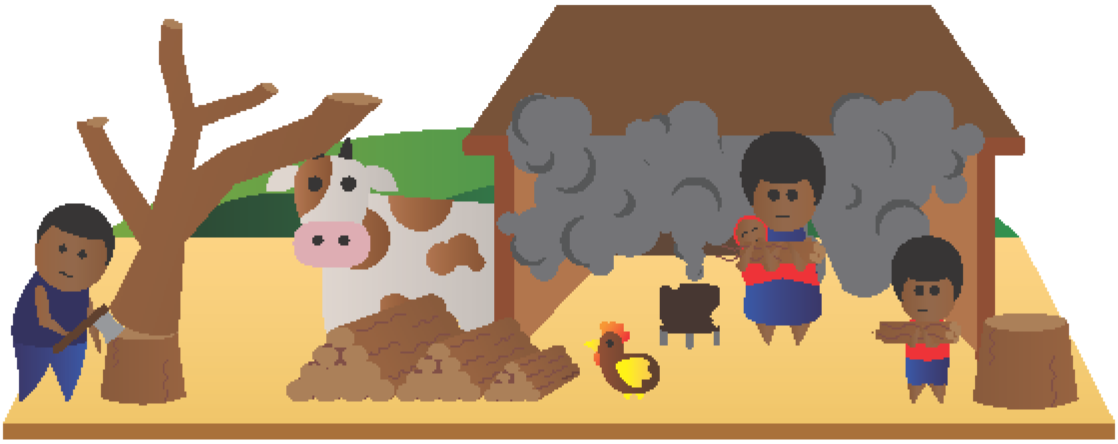
Cooking with a charcoal/wood stove



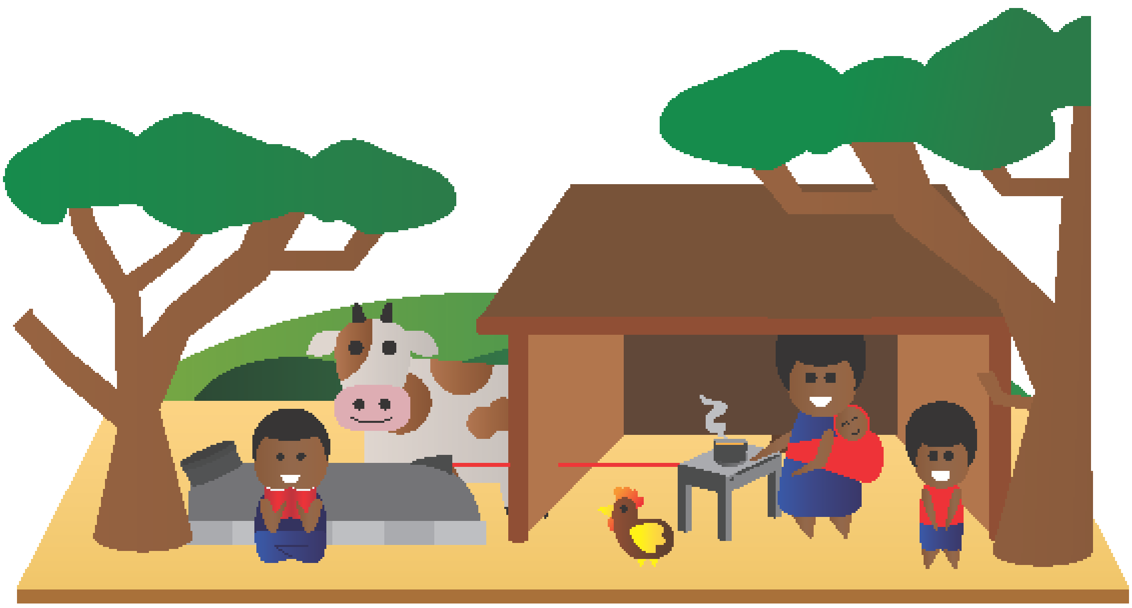
Cooking with a biogas stove

Benefits - Quick

When fed regularly biogas produces instant cooking fuel. This means less time is spent collecting fuel.



Cooking with a charcoal/wood stove



Cooking with a biogas stove

How Biogas Works

Biogas is a gas that is produced from the decomposition of organic waste such as animal waste, human waste and dead plants. There are many benefits to using biogas fuel, which make it a lot better to use than traditional charcoal and wood fuel cooking stoves. Biogas can also be used for lighting and electricity generation

Wet dead plants and human and animal waste are fed into the biogas digester, where they are broken down into a gas.

This gas is piped through to a connecting stove where it can be used as a clean, safe and quick cooking fuel.

Leftover waste from the digester can be used as a natural and efficient fertiliser for crops and plants or in aquaculture.