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

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1. Introduction

1.1. Central Rationale

The New and Emerging Technologies Research Competition (NET-RC) seeks to identify the key challenges and barriers that may be reducing the impact of technologies on the lives of poor people and help to identify some of the key technologies that could form the basis of further work. In this project we have considered energy production using small scale biogas digesters in Sub-Saharan Africa (SSA), a technology that is already improving the lives of poor people in many parts of the developing world (Polprasert, 2007), but has to-date had only limited uptake in Africa (Walekhwa et al, 2009).

The challenge does not lie in the development of the small-scale biogas digesters; the processes of digestion are already well understood and different designs for low-cost digesters are operational. What is needed is the translational research to make it possible for these digesters to become available to people in SSA who have little or no disposable income and access to only limited material resources (Akinbami et al, 2001). Development is needed of effective, safe and affordable methods for using small scale biogas digesters to provide household energy and improve sanitation in the range of special conditions found in SSA, while obtaining the maximum economic and environmental benefits from the digested products, which are an important source of scarce nutrients.

1.2. Demand for small scale biogas digesters in Sub-Saharan Africa

Interest in use of small scale biogas digesters in rural communities of SSA to treat and utilise organic wastes is increasing, with numerous organisations promoting their use for both socioeconomic and environmental reasons
(for example http://igadrhep.energyprojects.net/Links/Profiles/Biogas/Biogas.htm).
Small-scale biogas digesters have great potential to contribute to sustainable development by providing a wide variety of socioeconomic benefits (Mshandete and Parawira, 2009), including diversification of energy supply, enhanced regional and rural development opportunities, and creation of a domestic industry and employment opportunities (Rio and Burguillo, 2008). Potential environmental benefits include reduction of local pollutants, reduced deforestation due to logging for fuel, and increased sequestration of carbon (C) in soils amended with the digested organic waste (Lantz et al, 2007). Ecosystem services that are potentially delivered through implementation of biogas digesters in rural communities are C sequestration, improved water quality and increased food production (Ji-Quin and Nyns, 1996). Carbon can be directly sequestered in the soil through application of soil organic matter originating from the digested material (De Neve et al, 2003; Marks et al, 2009). Indirect C sequestration can also be achieved through reduced C losses due to logging as household fuel is replaced by methane produced by the digester (Mwakaje, 2008). Water quality can be improved through reduced runoff of waste material and reduced erosion of sandy soils due to stabilisation of the soil through increased input of organic matter (Yongabi et al, 2009). Food production can be improved by application to the soil of digested material containing readily available nutrients (Onwosi and Okereke, 2009). The productivity of the soil can also be improved through improved soil structure and water holding capacity achieved by the organic amendments of digested material to the soil (Mtambanengwe and Mapfumo, 2005; Fonte et al, 2009).

1.3. Risks associated with the use of small scale biogas digesters in Sub-Saharan Africa

Despite the high potential benefits, uptake of biogas digesters in SSA is small compared to other developing countries. A range of socioeconomic factors influence uptake (Walekhwa et al, 2009). Possible negative impacts are the potential for pathogens harboured in the digester slurry to infect humans who handle it or eat crops fertilised with it (Yongabi et al, 2009; Brown, 2006), the use of scarce economic and material resources in installation of digesters (Amigun and von Blottnitz, 2009), the potential for water pollution through losses from faulty digesters or from runoff of undigested material that has been applied to soils, and possible leakage of methane before complete combustion to CO_2, so increasing the global warming potential of the emitted gases (Rabezandrina, 1990).

Practical problems include prohibitive initial investment costs (Karekezi, 2002) and availability of materials for construction of digesters that will not leak materials or gases (Rabezandrina, 1990). Digesters must be designed to function efficiently in low rainfall conditions (Rabezandrina, 1990). The amount of fuel produced must be sufficient to meet the needs of the households, and this depends on the availability of feedstock from human, animal and plant sourced organic wastes (Rabezandrina, 1990). The use of the fuel produced and the digested product should be socially acceptable to the rural community if digesters are to be adopted (Fox, 1993). Political measures may be needed to encourage adoption, including training and capacity building programmes, flexible financing mechanisms and dissemination strategies (Karekezi, 2002; Greben and Oelofse, 2009).

1.4. Summary of approach

The possible benefits and risks associated with implementation of biogas digesters require further analysis if their full potential to alleviate poverty in SSA is to be realised. A full study requires a new multidisciplinary approach, bringing together expertise in engineering, hydrology, biology, social science, economics and systems-modelling. Engineering expertise is needed to identify optimum methods for implementing biogas digesters in different rural communities, focussing on locally available materials and efficiency of the digesters produced. Biological and hydrological expertise is needed to investigate microbial composition of the product at different stages through the digestion, fate of micro-organisms, nutrients and organic material applied to soils, changes in erosion and potential improvements in crop yields with application of digested product to fields. Economics is needed to assess household willingness to pay for the new technology, economic costs and benefits of introducing biogas, and impact upon rural livelihoods. Social science is needed to investigate the social acceptability of using biogas digesters in different rural communities. Systems-modelling is needed to determine the possible returns per household from fuel and use of the digested product as a fertiliser, and to integrate biological research into an estimate of the potential fate of soil C and N following application of digested product. This provides information about the material inputs and outputs from the digester and fertilised fields, which will allow an economic analysis of potential costs and benefits of using biogas digesters.

The work in this project has reviewed the potential sources of information and developed an analysis of potential costs and benefits of biogas digesters using information from the literature. Reviews of different factors influencing successful implementation of biogas digesters in SSA were presented at a 4-day workshop held at Makerere University, Kampala, Uganda. Key players researching into different aspects of biogas digesters and people working in extension, implementation of the technology and policy were invited to participate in the workshop. Following the workshop, selected participants were invited to contribute ideas on the implementation of small scale biogas digesters in SSA for incorporation into a fuller proposal for submission in Phase 2. The ideas were formalised at a half-day workshop, held at James Hutton Institute, Aberdeen, Scotland, and further refined at a 3-day workshop held at Addis Ababa University, Addis Ababa, Ethiopia.

1.5. Outputs

The outputs from the project are as follows:

- A review of the potential of biogas digesters to improve livelihoods and long term sustainability of ecosystem services in SSA
- A review of the position of biogas digesters in Uganda
- A review of the position of biogas digesters in Ethiopia
- Proposals for future work
    - A proposal to phase 2 of the DFID New and Emerging Technologies Research Competition on the potential of biogas digesters to alleviate poverty in SSA (focussing on flexible balloon digesters).
    - A proposal to the AUC-HRST scheme (by J.Mugisha, Makerere University, worth 842,345 Euros) on improving the uptake of small-scale biogas digesters in rural households in SSA.
    - A proposal to the AUC-HRST scheme (by Karsten Bechtel, CREEC, Makerere University, worth 1,012,681 Euros) on improving the design of small-scale biogas digesters for use in rural households in SSA.
- A review article on implementation of biogas digesters in SSA for submission to a peer-

reviewed journal,
- Plans for a special issue of a peer-reviewed journal, to be submitted early 2012.
- An extended multidisciplinary network of researchers working in different aspects of implementing biogas digesters in SSA.

1.6. Activities

The activities undertaken during the project to achieve these outputs include
- An interdisciplinary expert workshop on the potential of small-scale biogas digesters in SSA - Makerere University, Uganda, 24-28 January, 2011 (4 days) – see appendix A
- A grant writing workshop to prepare the DFID phase 2 bid on the potential of small-scale biogas digesters to improve livelihoods and long term sustainability of ecosystem services in SSA
- An interdisciplinary expert workshop on the potential of small-scale biogas digesters in SSA - Addis Ababa University, Ethiopia, 16-18 May, 2011 – see appendix B

2. The potential of biogas digesters to improve livelihoods and long term sustainability of ecosystem services in Sub-Saharan Africa

2.1. Biogas digesters in Sub-Saharan Africa and other parts of the world

(Greg Austin, Bob Orskov & Jecinta Mwirigi)

Biogas technology is an integrated waste management system that is a clean, renewable, naturally produced and under-utilised source of energy. Methane is produced through an anaerobic biological process of conversion, using any available organic material. The gas produced is similar to natural gas and is composed of 50-70% methane, the remainder being composed of carbon dioxide and traces of hydrogen sulfide and ammonia. It can be used for heating, cooking, electricity production, and vehicle fuel, and can be piped, bottled, stored, compressed, and even liquefied, providing on-site energy production, storage and access. The potential benefits to the household include improved food production; energy access; reduced deforestation, erosion and soil degradation; improved indoor air quality and sanitation; water reuse and recycling; reduction in odours and local job creation. The value of the organic fertilizer produced is a key issue, and has been estimated to be in the region of 5 times the value of the biogas. Less nutrients are typically lost during anaerobic digestion than during aerobic composting, making the digest a more nutrient rich fertilizer than aerobic compost. The number of biogas installations across Africa is increasing, largely in the domestic energy sector, due to national domestic biogas programmes in Rwanda, Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin and Burkina Faso, each with national targets of over 10,000 domestic systems to be installed in the next five years. However, technical, environmental, financial and social questions remain, and the rapid increase in the number of biogas installations means providing scientifically rigorous answers to these questions is of critical and urgent importance.

Due to the generally warm climate in Africa, at most locations ambient temperature is sufficient to maintain the fermentation process and no artificial heating is required, and biogas installations are generally based on psychrophilic (<20°C) or mesophilic (30-42°C) anaerobic digestion. Digesters available in Sub-Saharan Africa are of 3 main types: flexible balloon, floating drum, and fixed dome (figure 2.1). The choice of the design of the digester is a key determinant in the success of the implementation; if it is too expensive, poor farmers will not be able to risk making the investment; but if it is not robust and cannot be easily repaired, farmers will not see the long term benefits. The flexible balloon installations are relatively cheap (30-100 US$), but are liable to damage. Floating drum and fixed dome digesters are more expensive (700-1200 US$), but are more robust. Floating drum installations are effective, providing gas with a fixed pressure, which is good for domestic use, but can be more expensive and less robust than a fixed dome digester. Fixed dome digesters are more robust as they use no moving parts and can be constructed from local materials. The different types of designs should be objectively evaluated for each installation to determine the most appropriate choice. Technical factors that should be considered include gas tightness, water tightness, gas production, gas pressure, efficiency, water requirements, temperature sensitivity, scum release, sedimentation, super structure wear and tear, ability to co-digest various feedstocks; financial factors include capital cost (including installation) and operational cost; user factors, include satisfaction, time to initiate gas production from installation, convenience; institutional factors include ability to implement quickly, and quality assurance.

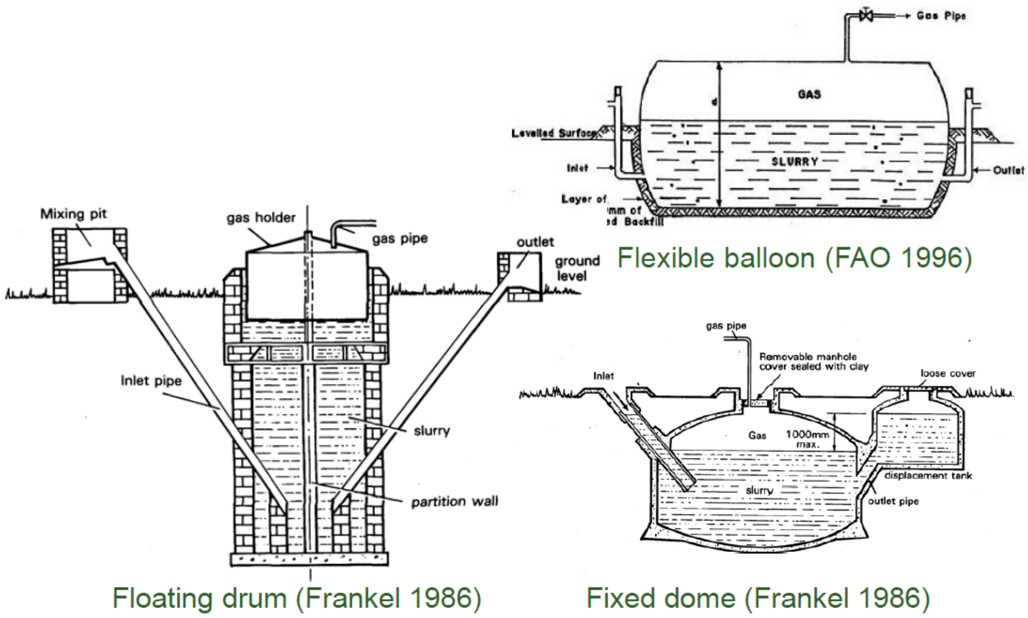

Figure 2.1. Small scale biogas digester designs available in Sub-Saharan Africa

Biogas technology at the household scale has largely converged around a fixed dome design philosophy. The current SNV supported national programmes are using fixed dome designs. A number of variations on the fixed dome design exists including Chinese, Deenbandhu, Camartec, Nepalese,and prefabricated (and hybrid prefabricated) designs. The SNV programmes use the Nepalese design in Rwanda; a modified Camartec design in Uganda, and Tanzania; the Kenbim design (a cross between the Nepalese and modified Camartec design) in Kenya. In India, the preference lay with floating drum designs for many years, but a programme is now underway to upgrade these to fixed dome, and to implement prefabricated or hybrid prefabricated digesters. In China ~40 million digesters have been installed and 6 million per year are planned using a fully or partially prefabricated fixed dome design. Prefabrication or hybrid prefabricated technology appears to be increasing internationally due to its rapid installation and the advantage of providing a valuable asset that can be reclaimed by investors on failure to repay loans. However, in Africa, the applicability of this more costly option remains to be proven.

By contrast in Vietnam, the emphasis has been on flexible balloon digesters. This highly successful national programme has involved integration of cheap biogas digester technology into holistic farming systems, including use of the nutrient rich digester slurry in fish ponds to grow algae to feed the fish and provide an additional source of food and income. Why is uptake higher in countries such as Vietnam, where the national programme has been highly successful? 80% of the population live in rural areas. The materials used in construction are either cheap (polythene used in flexible balloon digesters) (Zhu, 2006), or are highly subsidised (Rogers et al, 2006). Diversified sources of funding are also targeted, such as the clean development mechanism. A fixed dome biogas plant is capital intensive, and may be beyond the reach of the majority of households in developing countries. In Vietnam, there are 15000 – 20000 of the cheaper flexible balloon digesters (Zhu, 2006). These were initially supported by a 25% construction subsidy. Installations have been mostly in the south, which is a pig farming area; this type of manure is highly suitable to flexible balloon digesters as it is easily mixed into a structureless slurry. Key demonstration farms have been used to promote the flexible balloon digesters. However, since the withdrawl of subsidies, the rate of uptake has dropped significantly. In the North of Vietnam, fixed dome digesters are the predominant design. Farmers have small land holdings, and these digesters are low maintenance and require less space than balloon digesters. They also have a longer lifespan, but are more expensive than the flexible balloon design. In Vietnam, Zhu (2006) noted that recognizing the importance of biogas is not sufficient incentive to its adoption; an integrated farming system based around the biogas digester and the slurry it produces is more appealing. Factors resulting in high uptake in Vietnam therefore appear to be the provision of subsidies, the development of an integrated farming system in which the biogas digester is an essential component, and the use of a non-standardised approach in which it is recognised that different are appropriate in different conditions.

In Indonesia, an institutional framework exists to support the development of energy self–sufficient villages, a village that fulfils 60% of its energy demand. This utilises local energy, creates productive activities as a result of using local energy sources, and provides new employment opportunities. A number of important innovations have been achieved during these projects. Excess gas has been compressed into a gas tank, which is then used to distribute the spare biogas to households by motorbike, the motorbike also being run off biogas (Pertiwiningrum, 2010, pers.comm.). A different type of horizontal digester, a rigid pipe digester, is used. This provides many of the advantages of the flexible balloon, but without the problems due to lack of robustness. Cost of these digesters is around ~$250. Problems faced with the energy self-sufficient villages include problems with technical competence throughout the supply chain, lack of coordination among stakeholders from national to local level, non-comprehensive uptake of the policy at village level, and lack of long term support for the scheme throughout the lifetime of the digester. One solution is to create a supporting network involving universities, vocational schools, local businesses, and a corporate or social responsibility programme. The aim of the supporting network is operational management, organization, training of the service provider, financial support, repair and maintenance, and supply of spare parts. Recommendations based on experiences in Indonesia are to standardise the digesters used, and to encourage continuous improvement and innovation through research and development. A systematic and sustainable synergy should be encouraged among stakeholders as a supporting network mechanism. The digester should form part of a total solution to energy supply and farming needs.

The reasons for the success of the Vietnamese, Indonesian and Chinese programmes compared to the African experience require further analysis, itemizing the influence of financial, sociological, technical and environmental factors on the programme success.

2.2. Engineering issues

(Rethabile Melamu, Greg Austin, Linus Naik, Allison Kasozi, Harro von Blottnitz)

The operational design of a biogas digester is generally classified according to operation temperature (psychrophilic <20°C; mesophilic 30-42°C; or thermophilic (50-60°C); total solids content (wet 5-20% dry matter; dry > 20% dry matter); the nature of feeding and output operations (continuous flow or batch systems); the number of digesters or separate phases (single, double or multiple); and the digester layout (vertical tank or horizontal plug flow). The impact of the different designs options on factors such as rate of gas production, space requirement, pathogen reduction, management requirement, capital and operating cost, maintenance, and consistency of gas output determine the most appropriate design for a particular site. The engineering design process involves evaluation of the different designs to find the best solution for a particular context, and is done in 3 phases: concept design, consultation and detailed design. Concept design uses information about the needs, availability of feedstock, climate, seasonality and discharge parameters to suggest the reactor type, design a control strategy, complete a cost benefit analysis and estimate the initial investment costs. This is a lengthy process, and design software is needed to speed up this work and include socio-economic, and environmental factors into the analysis. Approval of the concept design is usually necessary before moving to the detailed design. The detailed design is informed by the concept design and provides detailed reactor specifications (including placement of the digester and materials used in construction), strategy for controlling and monitoring the digester (monitoring factors such as pH, temperature, agitation, hydraulic retention time, solid retention time, gas production rate and gas quality), a plan for maintenance (possible use of cleaning agents and annual inspection), a more precise estimate of investment needed and the sources of funding, and a comprehensive strategy for dealing with effluents and discharges.

2.2.1. Availability of materials for construction of biogas digesters

Hardware needed for construction of biogas digesters includes burners, metal drums and storage drums. If a flexible balloon type digester is adopted, materials needed are plastic linings, acrylic tubing, irrigation pipes, Teflon tape, adhesives, and sticker tapes. For a fixed dome digester cement, mud bricks, sand, gravel and shovels are required. Fixed dome or floating drum digesters can be constructed out of more local materials, but the cost may be higher. More studies are needed into the potential of local materials that can be used to produce low-cost flexible balloon type digesters as well as fixed dome digesters. More studies are also needed into possible starter cultures and substrates for digesters including animal and agro-industrial wastes, and waste-water with high microbial burden.

2.2.2. Integration of biogas into the farm unit

Contrary to Asia, biogas technology has not been very successfully promoted in Africa, and this is due to a range of social and technical reasons. The technology often needs high levels of skill and supervision for reliable operation and the daily labour input for its operation can be too demanding, particularly when it involves cow dung collection and mixing with water. These issues can be solved by efficient design of the biogas digester and integration of the unit into the farming / household system to require as little human intervention for operation as possible.

The raw material for digestion must be conveniently available on a daily basis (minimum 30 kg of cow manure or 15 kg of vegetable waste or any equivalent), otherwise the technology will not be viable. There must be a need for the energy (and/or fertiliser).The location of the digester should have suitable inlets and outlets to allow the introduction of organic waste and the use of the sludge or overflow water without a large input of labour. The digester should be positioned to minimise transport labour; the gas-line is easily extended (up to a point), whereas the transport of feedstock can be labour intensive. If the digester cannot be built adjacent to the shed, this may mean moving the cattle shed or kraal, or constructing a furrow with a cement base to carry the feedstock from the animal house to the digester. At the same time the digester should be as near to any other feedstock sources (such as the kitchen) as possible. Wherever possible digesters should be installed where there is a ready flow of wastewater (for example from restaurants, hostels), and wastewater should be used in preference to fresh potable water. Use of water containing detergents from kitchen could adversely affect gas production, so more experimental measurements on the use of waste water in digesters is needed. A wastewater pipe can be installed from kitchen area underground directly to the digester. Solids can be added directly without mixing if inlets and outlets are sized to prevent blockages. We need to utilise an appropriate design to ensure that we don't unnecessarily increase labour requirements, such as by fine chopping of materials. Every step of the process must be implemented to maximise efficiency, including the correct setting and use of appliances.

2.2.3. Co-digestion of feedstocks for maximum return

Co-digestion uses multiple feedstocks. The C:N ratio and pH of the digest can be adjusted by selecting an appropriate mixture of feedstocks. Co-digestion is key to improving waste management and sanitation. Different feedstocks have different gas yield potentials (figure 2.2). Materials with high C:N ratios, such as waste wheat and bread, typically have a much higher gas yield than materials with a low C:N ratio, such as cattle and pig manure. Co-digestion can be used to selectively improve the biological and nutrient environment in the digester, while increasing available gas and nutrients, and improving waste management. Further research is needed to identify suitable co-feedstocks, either to improve the quality of biogas or to maximise yield gas yield.

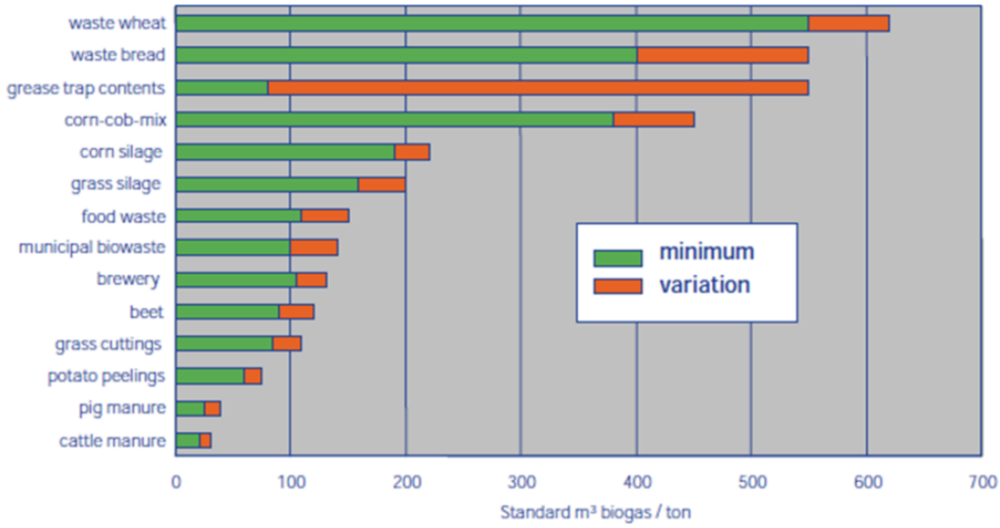

Figure 2.2. Typical gas yields of different feedstocks (after Austin, 2011)

2.2.4. Hardware developments to improve use of digesters

The technical features of a biogas digester that can differ in design are the inlet for organic matter, the outlet for sludge, the overflow and the output for gas. The target for most systems is to achieve the highest possible yield using the smallest possible volume in a productive and stable system. The types of digesters considered by this group are small scale digesters, suitable for use by the rural poor in SSA. This immediately defines the scale of the digester as small, the digester design as continuous flow rather than staged, with a short hydraulic residence time, using wet digestion, located in rural (or sometime urban) settings, and with no additional heating or agitation. The output will be primarily for cooking or lighting rather than space heating, and the feedstock will differ depending on location.

A number of different modifications of the same design of digester exist. A search on the World-wide web indicates 83 technology suppliers of floating drum digesters, and 140 technology suppliers of fixed dome digesters. One example modification of the fixed dome design is provided by AGAMA Energy, known as the Biogas Pro (figure 2.3). This is a prefabricated design, cutting on-site installation time from typically 25 days to 3. It also reduces the space requirement of the digester compared to built designs. However, it supplies work for a much smaller number of unskilled labourers in the installation. Quality is ensured by a 60 point quality control check at the factory. This design has a large inlet, which has the advantage of allowing feedstock to be added without the need for mixing or sieving. The design allows for a dry toilet connection. Aerobic post-treatment options include a reedbed soak-away, a compost pit or direct utilisation. The design uses building materials of fibre glass (expensive) and LLPDE (needed to make special connections). Effective consistent quality manufacture is improved by positioning the expansion chamber over the reactor; also having the advantage that it reduces the venting of methane to the atmosphere from the overflow. The design is very effective, but also expensive (~$6000). A new smart-top design that allows the base of the unit to be constructed from local materials, and the top to be fitted could potentially bring down the price while maintaining effectiveness.

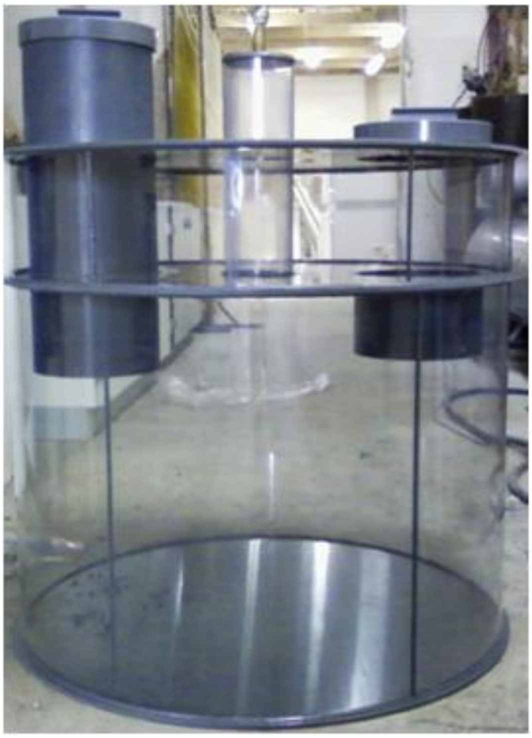

Figure 2.3. Biogas Pro digester, provided by AGAMA Energy (Austin, 2011)

A toolkit for use by the person providing support for the biogas digester is currently being developed at UCT (figure 2.4). This includes a suitcase to hold the kit, gloves for hygiene, a log book for recording outputs, pH strips (currently obtained from cheap strips used to determine the pH in pools), 25 kg of builders lime to adjust the pH, a pressure gauge and a sampling device. Other measurements that might be incorporated in the future include temperature measurement, microbial species identification using a dipstick, C and N measurement (eg. urine testing strips, soil N indicator strips; methane / CO_2 by a flame test). A starter culture could also be included to help solve digester start-up problems, as well as items to solve structural problems, such as spare valves.

Figure 2.4. Toolkit to help provide support for the biogas digester (Naik, 2011)

A smart monitoring system based on cell phone technology is also being developed at UCT. The aim of this is to ensure productivity and stability of small-scale systems, enabling quick response to solve digester problems. This has lead to the development of a cell-phone application and user interface. Developments of this system are still underway.

2.3. Socio-economic issues

(Jecinta Mwirigi, Johnny Mugisha, Bedru Balana, Klaus Glenk, Peter Walekwha)

There is a lack of basic cooking facilities, latrines and hygienic standards within Sub-Saharan; 80-90% of African households rely on biomass fuel and 72% do not use improved latrines (WHO, 2000). Biomass fuels require money or time to obtain them, and the lack of hygienic conditions results in health problems, indoor air pollution (392,000 deaths in Africa in 2000 according to WHO), contaminated (drinking) water, and lack of basic hygiene. Biogas digester technology is spreading fast in Asia but uptake in SSA has so far been slow, despite significant national and international efforts to support technology adoption (Ni & Nyns, 1995). Therefore, an integrated biogas, sanitation and hygiene programme has been initiated, aiming to provide a multitude of benefits to society; clean cooking for at least 10 million Africans, 5000 fewer deaths among women and children each year, a rise in agricultural production of up to 25%, at least 50,000 new jobs, household workloads being cut by two to three hours a day, better health and quality of life, fewer trees being cut down for firewood, more fertile soil, higher agricultural production, fewer greenhouse gas emissions, a cut in health costs between 60 and 100 Euros per family per year, a saving of 6,400 tons of fossil fuel per year, a saving of 3 to 4 million tons of wood per year and an annual reduction in greenhouse gas emissions of 10 Mtons of CO_2.

The scale of programme is substantial; within 5 years, 20,000 biogas plants are planned to be installed in Uganda alone. For the whole of Sub-Saharan Africa, the initiative aims to install 2 million plants within 15 years. In Uganda, a 5 year “roll-out” period is planned. However, economic factors, social perceptions and the acceptability of biogas as an energy source can have a profound impact on the success of implementation programmes. In many areas of Sub-Saharan Africa, biogas is considered to be a new and dirty technology. A social stigma exists against its use because of social beliefs. Many people consider the taste of the food cooked by biogas to be inferior to that cooked on a wood or charcoal stove. These socio-economic factors should be analysed before beginning a dissemination programme in a particular area, as in some places, the limitations of one or more of these factors could mean that implementation is unlikely to succeed. Efforts to introduce biogas digesters should be focussed in areas where socio-economic factors are most favourable, and the choice of digester design should be tailored to maximise the local chances of success.

2.3.1. Economic assessment of benefits and costs of biogas digesters in Sub-Saharan Africa

(Based on a cost-benefit analysis prepared for the Dutch Ministry of Foreign Affairs by Winrock Consultancy, which evaluates the national (Uganda, Rwanda, Ethiopia) and regional (Sub-Saharan Africa) integrated biogas and sanitation programs).

The costs and benefits were calculated as net 2007 values with a 3% discount rate. Financial costs and benefits were calculated for households and full economic costs and benefits were calculated at the societal level. The household level is important as it will inform the private decision to switch to an alternative technology. The societal level is of greater relevance to national and international agencies informing strategies to support the adoption of the technology. The study is based only on “average” household and so no heterogeneity of households is considered. Average “appropriate” size of biogas plant is specified for whole country as a fixed dome design, with a volume of $8m^3$, supplied by cattle dung and water. Note that the use of an average plant size does not account for heterogeneity in household needs, availability of materials, and transportation and hence installation costs. The costs may vary with availability of wages, labour and specialised skills. There is a need to incorporate potential heterogeneity in a full cost / benefit analysis. There is also a shortage of the data needed for some estimates, and so many parts of the calculations are based on assumptions. There is an urgent need for the research required to fill these data gaps to be undertaken.

The costs and benefits at the household and societal levels are summarised in table 2.1. The cost benefit analysis suggests that biogas digesters are a worthwhile investment from a private and in particular a societal perspective. Societal analysis of costs and benefits is sketchy but the benefit to cost ratio is large; a more detailed analysis may further increase this ratio. Issues remain with the financial cost benefit analysis; there are many barriers to investing into relatively uncertain future benefits and this may hamper the progress of national programmes.

Level of analysis	Costs	Benefits
Household (financial)	Cost of a biogas plant at the subsidized rate	Cooking and lighting fuel savings
	Cost of a pour-flush sanitary latrine	Time saving due to biogas
	Repair and maintenance costs of plant and latrine	Saving in household's health related expenditures
	Cost of extra time consumed due to biogas plant and latrine installation	Income effects of improved health
	Cost of hygiene materials purchased by the household	
	Financing costs, if applicable	
Societal (economic)	Full cost of a biogas plant and latrine	Cooking and lighting fuel savings
	Repair and maintenance cost for biogas plant and latrine	Chemical fertilizer saving (low level of application: hence not included in financial analysis)
	Cost of extra time due to biogas plant and latrine installation and operation	Time saving due to biogas and latrine (fuel collection, cleaning and cooking, latrine access)
	Cost of hygiene materials purchased by the household	Saving in all health-related expenditures
	Technical assistance	Time savings due to improved health
	Program costs related to biogas and hygiene, including financing	GHG reduction
		Local environmental benefits

Table 2.1. Financial and economic costs and benefits associated with biogas digesters and sanitary latrines.

2.3.2. Socio-economic constraints to adoption

Socio-economic status is based on family income, parental education level, parental occupation and social status (contact within the community, group association and community perception of the family) (Damarest, et al, 1993). In a review of socio-economic factors affecting adoption of biogas digesters in 5 countries in Sub-Saharan Africa (table 2.2), most factors affecting adoption were associated with costs and ability to pay; family income, size of farm, construction costs, costs of traditional fuels and availability of credit facilities. Other factors were associated with availability of feedstock; number of dairy cattle, average cost of a dairy cow, and land and water availability. Education, awareness, and type (e.g. age and sex) of household head were also factors affecting adoption. There is a need to address country specific requirements for widespread adoption of biogas digesters to be achieved. Costs and subsidies for purchase are important issues that could have a strong impact on adoption. Cheaper materials are needed for construction, and credit facilities are required. Reduction of retention time from 60 to 30 days reduces by half the size of the plant needed, with a significant reduction in construction cost. Awareness of the value of biogas digesters needs to be addressed, using different methods of dissemination, such as electronic and printed media, workshops, field days, demonstrations, and farmer to farmer contacts.

Costs and ability to pay - Analyses of costs and benefits of biogas digesters are often unreliable and uncertain (Quardir et al., 1995); this does not help to promote user confidence and may inhibit future uptake. Only designs appropriate to the specific conditions will perform satisfactory and have a favourable cost-benefit ratio. The size of farm has an impact on uptake; agricultural productivity is inversely related to farm size due to the option to use family labour on a small farm (Berry and Cline 1979; Feder, 1985; Lipton 1993). This then has a similar impact on the ability of the farmer to use family labour to feed the biogas digester, and so impacts successful operation of the digester. Availability of the labour required for daily operation and maintenance of the digester determine whether the digester will be operational in the long term. Labour is needed for acquisition of dung or other organic materials, collecting water for mixing with the dung, feeding the digester, regular maintenance, and supervision, storage and disposal of slurry. The availability of cheap and reliable appliances, and strong technical support, further increase uptake and long term use of the digester (Kuteesakwe, 2001). The cost of alternative fuels available to the household has a strong impact on adoption: the higher the price of energy replaced by biogas, the higher the probability of adoption. As fuel wood becomes scarcer, biogas becomes a more attractive option. The initial investment cost is probably the biggest constraint to adoption; in Tanzania, a fixed dome design costs between 700 and 1200 US$, and most rural households and subsistence farmers would consider this an unaffordable luxury unless they receive external support. However, substantial support would be required by governments and aid agencies, and the experience in Asia has been that subsidies do not necessarily encourage long term uptake. Low cost flexible balloon installations, if possible utilising local materials to reduce production and installation costs, might provide a more economically acceptable solution. A promotion scheme is needed to publicise the multiple benefits of digesters including clean energy, improved sanitation and the valuable fertiliser provided by the slurry. Important marketing issues that must be addressed include packaging, distribution, commercialisation, availability, affordability of spares and aftercare service.

Availability of feedstock - The source of substrate for the digester is an important factor; the source must be reliable and sufficient. In Uganda, where cattle manure is a major source of substrate, the number of livestock kept and the use of extensive grazing systems can limit benefits from a biogas digester. African countries generally have relatively low numbers of cattle, compared to India and China who produce 28% and 19% of the world's cattle respectively (USDA/FAS, 2008). (Note that to be directly comparable, these numbers should be reanalysed in terms of number of cattle per head of population.)

Availability of land and water – A possible barrier to uptake is unavailability of land and water (Quardir et al, 1995). The amount of land required for setting up an integrated biogas unit (biogas plant, animal unit for substrate, fodder unit to sustain the animal unit) can be limiting in some overpopulated areas. All units need to be in close proximity for efficient biogas production. Approximately equal amounts of water and dung are required, amounting to ~60 litres of water per cow per day. In Uganda, 76% of households have water within 1km of their homes (Pandey et al., 2007), but in other parts of Sub-Saharan Africa, water may be more distant. However, re-use of water collected for other purposes (such as washing) can help to alleviate this problem. Community driven approaches to water supply have been initiated (World Bank, 2011), including rainwater collection methods (Kuteesakwe,2001), and these have great potential to increase uptake.

Education, awareness, and type of household head - Awareness of the value of biogas may be another factor inhibiting uptake (Bhat et al.,2001). Multiple agencies are currently attempting to increase awareness, including private enterprise, promoters, catalysers and user interest groups. Lack of education may present a barrier to uptake. Although formal credit markets have become increasingly accessible to farmers, farmers lacking a high level of literacy may find the complicated borrowing procedure and paperwork a major disincentive (Vien, 2011). This is supported by the observation that adoption increases with literacy rate (Bhat et al., 2001). There is an association between the rate of uptake and gender. There is enormous complexity and heterogeneity between different communities in Africa, so that few lessons about the impact of gender are transferable across villages, much less across the continent (Doss, 2001). However, it is clear that use of biogas encourages diversification of household labour from firewood collection, which is primarily done by women, to a greater variety of tasks that may be shared between the man and the woman (Kuteesakwe, 2001). An additional important factor that determines uptake is the permanence of the householder (Vien ,2011). If the householder has no land tenure, or is transient in some seasons, uptake and successful operation of the digester will be lower because the farmer is not likely to be able to make full use of the digester (Vien, 2011).

	Kenya (Mwirigi et al, 2009)	Nigeria (Akinbami et al, 2001)	Uganda (Walekhwa et al, 2009)	Tanzania (Mwakaje, 2008)	Sudan (Omer & Fadalla, 2003)
Family income ↑	↑				
Size of farm ↑	↑		↓		
Construction cost ↑		↓		↓	↓
Cost of traditional fuels ↑			↑		↑
Credit facilities ↑	↑				↑
Number of dairy cattle ↑	↑	↑	↑		
Average cost of a dairy cow ↑	↑				
Water availability ↑				↑	
Education and awareness ↑	↑	↑		↑	↑
Age of household head ↑	↑	↓	↓		

Table 2.2. Socio-economic factors affecting adoption of biogas digesters in 5 countries in Sub-Saharan Africa

2.3.3. Techno-economic feasibility of biogas in urban areas

A techno-economic assessment of the feasibility of communal scale, urban biogas digesters in Nairobi has been completed. A similar approach could be applied to smaller-scale rural installations. The capital costs are estimated by comparing to the costs of existing technological facilities using the cost-capacity (Lang) factor approach. Recent work in Africa suggests a cost-capacity scaling factor of 1.2 is applicable, suggesting economies of scale on scaling up biogas installations in Africa. More statistical data is needed to refine current economic understanding. The operating costs can be estimated from the costs of labour, maintenance, repairs and insurance, contingency costs, and variable organic waste buying or tipping fees. Biogas production is estimated from the total solids, volatile solids, and the biogas yield with respect to volatile solids, taking into account the plant's own gas and electricity consumption depending on operational needs and conversion efficiencies where the end product is electricity generation (as is likely in urban communal biogas installations). These sets of data allow the plant capital pay-back period to be estimated along with other economic indicators such as returns on investment and annual revenue streams. Preliminary assessments indicate that at the current technology levels, for such installations to be feasible in Nairobi, current national renewable energy feed-in tariffs will need to increase and tipping fees will be necessary for operational costs. This example is likely to be representative of the situation in many other African urban areas and cities.

2.3.4. Access, poverty and equity issues

Conventional approaches define poverty as 'low income or low consumption'. Over recent decades poverty concepts have changed to include multiple dimensions of deprivation and wellbeing. WDR (2000/01): "Attacking Poverty" sets out a comprehensive assessment on understanding poverty and its causes. Poverty encompasses not only low income and consumption, but also low achievement in education, health, nutrition, and other areas of human development. Four major dimensions of poverty are included: 1. lack of opportunity (material deprivation); 2. lack of capability (low achievement in education and health, malnutrition); 3. vulnerability (low level of security); 4. being voiceless and powerless.

While lack of opportunity and capability are well measured, vulnerability is not appropriately measured and being voiceless and powerless is not measured at all. Income or consumption poverty is measured by the World Bank using the "international poverty line", based on consumption or income data from 96 countries. An income of $1 / day is defined as low income, while $2/day is defined as low to middle income. These levels are only useful as indicators of global progress as there are huge inter and intra country variations. The cost of basic needs approach (eg Foster, Gree & Thorbecke) aggregates a food and non-food poverty components, to provide indices for absolute poverty, poverty gaps, and the severity of poverty. A weighted poverty index based on multiple indicators of poverty (eg Zeller et al, 2006) aggregates a range of quantitative and qualitative poverty indicators into a single poverty index. Examples of this are the HDI based on longevity, knowledge and a standard of living (UNDP); and the HPI based on a short life, lack of basic education and lack of access to public and private resources (UNDP). Another approach uses community ranking of households according to their wealth; this is a useful approach for identifying vulnerable groups within a community.

The benefits of biogas digesters can be expressed in terms of poverty indicators. If households spend less time in collecting wood and more time generating valuable income this increases the poverty indicator INCOME. Switching to cleaner fuels can reduce health risks, so increasing the poverty indicator HEALTH/LIFE EXPECTANCY. Spending less time collecting wood can allow more time for children's education, so increasing the poverty indicator KNOWLEDGE/EDUCATION. Finally, the potential environmental improvements increase the poverty indicators PRODUCTIVITY INCREASE and INCOME.

Two issues impact access to biogas technology: 1. technical potential and 2. economic potential. Heegde & Sonder (2007) suggests availability of dung and water to run a biogas installation are two basic requirements. For a biogas plant to be attractive to a household, it should be able to provide at least 0.8 to 1 m^3 biogas daily. To generate this amount of biogas, the household should have 20 to 30 kg of fresh dung available on a daily basis. An African household would need at least 3 or 4 night-stabled cattle to achieve this. This requirement is met by a large percentage of households, especially in East Africa.

Issues that must be considered further to increase accessibility to the rural poor are

- Can the poor afford the initial investment and maintenance costs?
- Do the poor have access to finance/credit?
- Is there commitment from national governments in disseminating the technology?
- Are the NGO initiated Biogas schemes sustainable?
- What is the economic efficiency?
- Is there potential for reducing costs by working at a larger scale?
- What potential is there for improving cost-effectiveness?

There is a need for further research into behavioural studies (choices and preferences) including experimental economics, quantification issues (capturing various costs & benefits components), socio-economic design mechanisms, barriers to uptake, knowledge transfer (awareness, training, and participation).

2.3.5. Marketing approach

Another reason for low adoption of digesters in Africa is that the technology is too expensive for wider dissemination, especially to low-income target groups. This problem could be addressed by the extension approach chosen: one possible, but controversial approach is to start where the money is (just like in any other new business), rather than targeting the poorer households. Whether we are aiming at full energy offset or partial fuel substitution by biogas has an influence on how and what we communicate to potential beneficiaries, and what technologies we use. A precondition to adoption must be that the customer has the necessary funds for the investment available. Whether this is achieved by targeting richer households, by subsidising the more expensive but robust designs of digesters, or by opting for less robust but more affordable digesters is still a matter for debate. Further socio-economic research is needed to inform these decisions.

2.4. Environmental Issues

(Robin Matthews, Madhu Subedi, Jo Smith, Kenneth Yongabi, Lisa Avery, Norval Strachan, Sean Semple)

The two requirements of any rural household that can be the source of environmental problems are the requirement to meet the household energy demand and need to dispose of organic wastes. In Sub-Saharan Africa 90-100% of the household energy demand is for cooking fuel (Davidson and Sokona, 2001), and the percentage of the cooking fuel obtained from fuel wood is between 75 and 100%, depending on country (World Bank, 2000; Omer & Fadalla, 2003). As the population in an area increases, collection of wood for fuel can result in deforestation, which results in loss of biodiversity and reduced carbon stocks held in the trees. When fuel is burnt to release energy, inefficient cook stoves can result in poor household air quality, which is detrimental to health. Disposal of undigested organic wastes can introduce pathogens, particulates and high levels of nutrients into drinking water. If these wastes are used as a substrate for anaerobic digestion, the level of pathogens reaching drinking water can be greatly reduced, the nutrients fixed into a slow release organic fertiliser, and the nutrition of crops and carbon content of soils greatly improved. Furthermore, the slurry output from the digester can be used to fertilise algae required to feed fish, so providing an additional source of income.

The potential environmental benefits of a biogas digester to the householder are in the provision of energy, the disposal of organic wastes, the improvement of air quality and the provision of a valuable organic fertiliser. To the wider community, the benefits include reduced loss of biodiversity and carbon due to deforestation, improvement in water quality and increased carbon sequestration in the soil. However, whether these benefits make it worthwhile for the householder to invest in a biogas digester, or for the wider community to support the installation of digesters must be quantified, and balanced against socioeconomic costs and benefits.

However, biogas digesters can also introduce potential risks to the environment. These include contraction of diseases due to increased handling of fresh wastes and the digested product, possible pollution of water courses due to leaks of organic waste from faulty digesters and incomplete sterilisation of slurry during digestion, and increased global warming due to leaks from faulty digesters and intentional venting of methane from some designs to avoid pressure build up. These issues are complex, and rigorous quantification of the different factors is needed to ensure the huge potential benefits of biogas digesters is realised.

2.4.1. Deforestation

Globally, 55% of the wood extracted from forests is for fuel, and fuel wood is responsible for 5% of global deforestation (FAO, 1999). Reductions in access to fuel wood supplies can negatively affect poor subsistence users as well as adversely affecting those generating income from fuel wood to bridge their income between seasons. In the 1970s, population pressures and increases in oil prices were already considered to be major drivers of deforestation (Arnold et al, 2003). It was estimated that tree planting in Africa would need to increase by a factor of 15 to meet the predicted 2000 demand for fuel wood (Anderson and Fishwick, 1984). There was a resultant increase in woodlots on communal land, but these initiatives largely failed because they were often commercialised, and the very poor could not afford what previously had been free. Improved cook stoves were provided, but were not reliable. Therefore, other forms of energy were subsidised. However, Arnold (2003) suggested that although fuel wood shortages did exist, much of the fuel wood collected was obtained from land cleared anyway for agriculture, dead and fallen wood, and supplies from trees outside forests (e.g. agro-forests). Other supplies, such as dung and crop residues are also used. Therefore, deforestation was not occurring at the rate initially predicted. Problems appear to relate to access rather than supply of fuel wood. Since the 1990s, concerns have centred on urban demand and the consequent reliance on charcoal.

Globally, projections based on modelled values suggest that fuel wood consumption has now peaked, and may even be in decline in some countries (Broadhead et al, 2001). However, in Africa, the consumption of firewood and charcoal continues to increase, with fuel wood consumption predicted to increase by 2030 to over 137% of the 1970 rate, while charcoal consumption is expected to increase to over 5 times the 1970 rate. This is especially worrying, as the process of charcoal production means that more wood is used in providing energy from charcoal than would be needed for firewood. Furthermore, by 2030 the number of people in Africa relying on biomass for cooking and heating is expected to increase to over 140% of the 2000 rate.

Woodfuel production (selling of woodfuel as a product in the market) has increased in Africa since 1961 by over 185% (FAO, 2011). This is not evenly distributed, with an increase of 8-1452% in 46 countries, and a decrease by 33-98% in 6 counties. Charcoal production (selling of charcoal as a product in the market) has increased during the same period by 534% (FAO, 2011); an increase in 50 countries of 75-2290% and a decrease in 2 countries by 37-90%. This change is highly correlated to population (FAO, 2011; UNDP, 2010); for woodfuel the linear regression between production and population has a value of R^2 = 0.61; for charcoal, the R^2 value is 0.77.

Income levels and fuel prices are the main determinants of the amount of fuel wood used per capita; the use of firewood and charcoal being highest in low income households, and the use of coal, kerosene, LPG and electricity being highest in high income households (Barnes et al, 2002). Although there is a relationship between income level and use of woodfuel and charcoal, the relationship to gross domestic product is not clear, perhaps because a high GDP is often not evenly distributed in the population (FAO, 2010; UNDP, 2010). Models predict that woodfuel consumption will increase to 109% of the 1970 value by 2030; and charcoal consumption to 470% (Broadhead et al, 2001). This is again highly correlated to population (for both woodfuel and charcoal, R^2 for the linear regression with population is 0.98), although this may reflect the nature of the model used to derive the future predictions (Broadhead et al, 2001; FAO 2010).

Convenience, price and reliability of supplies determine whether a household will change to other sources of fuel, both charcoal and wood consumption declining with increase in income. Almost all African countries still rely on wood to meet basic energy needs; fuel wood supplies 60-86% of African primary energy consumption and 90-98 % of residential energy consumption in most of sub-Saharan Africa. The per capita use of fuel wood is higher in Africa than in many other parts of the world (0.89 m^3/capita/yr compared to 0.3 m^3/capita/yr in Asia).

The UN REDD programme aims to link global agreements into local action to reduce emissions from deforestation and forest degradation. The potential for REDD to be used to promote biogas requires further consideration, especially with respect to the urban poor, who create a demand for charcoal because it is more easily transported from the forest to the towns. The rate of deforestation in Sub-Saharan Africa requires reanalysis, using the most recent statistics and the best available models.

The forest area available to provide woodfuel and charcoal is predicted to decrease by 11% between 2010 and 2030, whereas the total woodfuel required (assuming 7 t woodfuel is required to produce 1 t charcoal – FAO 1987) is predicted to increase by 24%. Assuming 1 ha of tropical high forest is required to produce 67.5 t of woodfuel (FAO, 1987), this would equate to an increased demand on forestry in Africa of 2521 kha between 2010 and 2030. This trend in woodfuel production and consumption is not sustainable in the longer term. Therefore, any reduction in woodfuel consumption as a result of biogas production might be expected to have a favourable effect on reducing deforestation. However, this analysis does not consider the wood obtained from land cleared for other purposes, dead or fallen wood, or other types of forest such as social-forests or agro-forestry. To account for the use of dead or fallen wood, the area required to meet the woodfuel demand should instead be calculated from the ratio of the rate of carbon sequestration in trees and the rate of demand for woodfuel:

$$\text{Area required to meet woodfuel demand (ha)} = \frac{\text{Rate of demand as woodfuel (t C / yr)}}{\text{Rate of C-sequestration in trees (t C / ha / yr)}}$$

The rate of carbon sequestration in trees can be obtained from key characteristics of typical species found in SSA. The rate of C demand as woodfuel can be calculated from the total energy demand for the country, converted to be in terms of carbon using the energy in each tone of wood and the percent carbon in the wood:

$$\text{Rate of C demand as woodfuel (t/C/yr)} = \frac{\text{(\% energy demand supplied by woodfuel) /100} \times \text{Energy demand per capita (MJ/capita/yr)} \times \text{Population (capita)} \times \text{\% C in wood/100}}{\text{Gross heat combustion (MJ/t}}$$

This provides an estimate of the total area required to supply the demand for woodfuel, accounting for the rate of uptake, which includes collection from fallen wood. The rate of deforestation attributable to woodfuel demand alone is then determined by subtracting estimates of the land cleared for other purposes. The next stage in this study is to collect the data needed to populate this equation for the different countries in SSA.

The interaction of animals with forests can increase carbon sequestration in the soil, which in turn can influence water holding capacity and thus growth of trees and fruit (eg coconut, oilpalm). It is important that organic matter is returned to the soil to avoid depletion of soil organic matter. This has been a problem in Ethiopia for many years due to a high proportion of manure being used for fuel. Depletion of soil organic matter and so also reduction in water holding capacity is particularly detrimental in dry years when the water held in the soil can limit crop yield. Biogas has great potential to reduce losses of soil organic matter by replacing the use of dung as a fuel with biogas. This in turn has great potential to improve soil fertility and crop production, and reduce soil degradation and erosion.

2.4.2. Carbon sequestration in soils

Carbon sequestration in the soil, not only removes carbon dioxide from the atmosphere, but also increases crop productivity by increasing the water holding capacity of the soil (Batjes et al, 1996), improving the aggregate structure (which favours root exploration and makes the soil less susceptible to erosion and loss of nutrients - Renshaw et al, 2006), and increases the supply of nutrients from the decomposing organic matter (Smith et al., 2010).

When organic matter is added to soil, it decomposes under aerobic conditions to release carbon dioxide. The amount of carbon sequestered is a balance between the inputs of organic matter and the rate of decomposition. The organic inputs to the soil depend on plant inputs (which are affected by crop nutrition, water availability and crop management) and organic amendments (either as aerobically composted organic wastes, as slurry from a biogas digester, or as charcoal produced by pyrolysis). The rate of decomposition depends on soil temperature, moisture, pH, salinity and clay content (Smith et al., 2010). The rate of decomposition increases exponentially with temperature up to a maximum rate at about 30°C (Jenkinson et al, 1987). Increases in the soil moisture content result in an approximately linear increase in the rate of decomposition until just below field capacity (Stanford & Epstein, 1974). Above field capacity, the rate of decomposition tends to decline as the soil becomes more anaerobic. The rate of decomposition declines with decreases in soil pH below ~pH 5 (Leifeld et al, 2008). As salinity increases, the rate of decomposition decreases exponentially (Setia, et al, 2011). The clay materials in the soil provide physical protection to the organic matter, and so impact the proportion of the decomposing material that is lost to the atmosphere, so affecting the rate of sequestration (Coleman and Jenkinson, 1996).

The organic carbon content of soils in Sub-Saharan Africa tends to be low due to the high temperatures, low clay contents (or cation exchange capacity) and low organic inputs due to poor crop nutrition. However, increasing the organic inputs, increases the steady state carbon content, and so sequesters soil carbon. If organic inputs were increased, for instance by adding material from a biogas digester to the soil, the carbon content of the soil would increase until it reached a new steady state level; after that no more carbon would be sequestered unless the organic inputs were further increased. The sequestered carbon is not a permanent store; it will only remain in the soil while the balance between the organic inputs and the rate of decomposition remains the same. If the organic inputs were reduced to their original level, for instance because the material from the biogas digester was no longer available, the amount of carbon held in the soil would return to its original level. Furthermore, if the rate of decomposition increased, for instance due to increased temperatures associated with climate change, the amount of carbon held in the soil would also decrease.

The rate of decomposition of material added to the soil also depends on the quality of the organic matter. If sufficient nutrients are available to allow decomposition, fresh material tends to decompose more quickly than material that has been composted or digested. Composted and digested material decomposes more quickly than material that has been converted to charcoal, which is highly recalcitrant. Further work is needed to determine the amount and decomposability of material produced by aerobic composting, anaerobic digestion and pyrolysis, so allowing the carbon sequestrated following the different treatments of a unit of fresh organic matter to be estimated. The nutrient content and the rate of nutrient release from organic waste depend on the source and treatment of the material. Further lab analyses and field trials are needed to determine differences in nutrient availability from material that has undergone the different treatments. This information is of crucial importance if the value to the farmer of compost, digest or charcoal is to quantified and compared.

2.4.3. Fate of Pathogens

Anaerobic digestion is carried out by facultative and anaerobic organisms. Whereas anaerobic organisms use no oxygen for oxidative metabolism, facultative organisms use both aerobic and anaerobic metabolic pathways. As shown below, aerobic respiration releases more energy per molecule of glucose than anaerobic respiration, so facultative organisms will tend to use aerobic pathways whenever sufficient oxygen is present.

Aerobic respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6\ H_2O$ (2880 kJ)

Anaerobic respiration: $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ (120 kJ)

An anaerobic digester contains a synergistic community of microorganisms that digest the organic matter to produce methane. The process is carried out by methanogens (archaea), bacteria, fungi and protozoa. Anaerobic digestion is complex, but can be summarized in 4 phases: conversion of the complex organic molecules contained in the organic waste to monomers (hydrolysis); monomers into organic acids (acidogenesis), organic acids into acetic acid (acetogenesis), and finally acetic acid into methane (methanogenesis). Hydrolysis is carried out by a number of bacteria, protozoa and fungi using exoenzymes. Fats are broken down into fatty acids and glycerols; carbohydrates into sugars; proteins into amino acids and sugars; and cellulose into sugars. Acidogenesis and acetogenesis are carried out by bacteria. Acetogenesis is often the rate limiting step in methane production. The soluble organic acid is oxidised in an anaerobic environment and produces H_2 as a by-product. This process requires the reduction of NAD to NADH, which cannot be regenerated in the presence of hydrogen and has a negative thermodynamic yield, for example

Acetogenesis of ethanol: $C_2H_5OH + H_2O \rightarrow H_2 + 2CH_3COO^-$ (-19 kJ)

The energy for this process is provided by methanogenesis:

Methanogenesis: $H_2 + CO_2 \rightarrow CH_4 + H_2O$ (131 kJ)

$CH_3COOH \rightarrow CH_4 + CO_2$

Other commonly used substrates for methanogenesis are formate and methanol. Methanogens are obligate anaerobes, microorganisms that live and grow in the absence of molecular oxygen, some being killed by the presence of oxygen. Therefore it is important that the environment of the digester remains completely anaerobic. Methanogens are from the domain archaea, classed as hydrogenotrophic, acetoclastic or methylotrophic, depending on the substrate used. The optimum pH for methanogenesis is around neutral, meaning that the process of methane production is inhibited at very low or high pH.

Any of these 4 phases can become the rate limiting step to the anaerobic digestion, and understanding the microbiology helps us to use this information. If the hydrolysis phase is limiting digestion, selecting and processing a feedstock to favour hydrolysis may increase the rate of biogas production. If, on the other hand, it is acetogenesis that is the rate limiting step, other strategies may be needed, such as warming the digester to provide more energy to the endothermic reaction. There is great potential for using innocula of the appropriate micro-organisms or introducing organic materials that favour different phases of the process to speed up the rate limiting step and so improve biogas production.

Handling and application to crops of untreated animal waste is widespread in Sub-Saharan Africa. Diseases caused by contact with untreated animal wastes include skin diseases, such as cutaneous erysipelas (common name whitlow). This is caused by *Erysipelothrix* rhusiopathiae, a gram- positive, catalase-negative, rod-shaped bacterium which is present in animal wastes and grows under both aerobic and anaerobic conditions. Infections caused by intestinal worms, such as the parasitic nematode worm, *Ascaris*, which causes ascariasis, also results from contact with untreated animal waste, resulting in the exacerbation of communicable diseases such as typhoid, malaria, diarrhoea, dysentery and cholera. Other diseases commonly transmitted by contact with animal waste include bacterial diseases such as *Campylocbacter* spp and *Salmonella* gallinarum. Microscopy analysis of well water, raw slurry from dairy cattle and treated slurry after 4 weeks digestion, showed that the concentration of aerobic mesophilic bacteria was reduced by treatment of slurry from dangerously high levels to levels that were considered safe for humans and were significantly lower than in the well-water (Yongabi et al, 2009). Levels of E Coli and Coliforms were also reduced to safe levels by treatment of the slurry. Microscopy analysis of raw and treated chicken slurry also showed that biogas digestions reduced E.coli and Coliform counts, and the ova of *Ascaridia* spp, cysts of *Eimeria* spp, and other nematode like worms to safe levels (Yongabi et al, 2009). Further analysis of pathogen levels following treatment of organic wastes using the most recent biological methods is needed to ensure sterilisation of organic wastes is sufficient to allow them to be safely applied to food crops. This is especially important if human waste is to be included in the digester. Using human wastes presents sociological barriers, and greater dangers associated with transmission of pathogens. The value of human waste may not be high compared to that of dairy cattle. However, because of the potential for biogas digesters to improve sanitation and reduce pathogens in the water courses that originate from human faeces, the long term possibilities of using human waste should be considered further.

Health problems associated with spread of human wastes can occur due to pit toilets becoming overfull due to inadequate depth and toilets being cited too close to water sources. Human waste can also leach into ground water from a functioning pit toilet if cited on a highly permeable soil type. Contamination of groundwater and reservoirs by running storm water and flash floods can result in significant sporadic pollution events (such as reported in Malawi in 2009 by Pritchard et al, 2009). The type of contamination includes enterobacteria, enteroviruses and a range of fungal spores. Some key human/animal pathogens include *Salmonella typhi*, *Staphylococus spp*, *E. coli*, *Campylobacter coli*, *Listeria monocytogenes*, *Yersinia enterocolitica*, *Hepatitis B* and *C* viruses, *Rotavirus*, *Aspergillus spp*, *Candida spp*, *Trichophyton spp.*, *Cryptosporidium*, *Mycobacteria*, *Toxoplasma* and *Clostridium botulinum*, many of which are zoonoses i.e. they can be passed between animal and human populations. Cattle slurry introduces a range of pathogens including *Clostridium chavoie* (black leg disease); *Ascaris ova*, *E. coli* and *Salmonella spp*. as reported in cow dung slurries in Bauchi state, Nigeria (Yongabi et al., 2003); *Salmonella spp*, *E. coli*, yeasts and aerobic mesophilic bacteria in poultry wastes in Cameroon (Yongabi et al., 2009). Pathogen prevalence in the environment is affected by local climate, soil type, animal host prevelance, topography, land cover and management, organic waste applications and hydrology (e.g. Gagliardi and Karns, 2000; Jamieson et al, 2002; Hutchison et al, 2004; Tyrrel and Quinton, 2003; Tate et al, 2006).

Installation of biogas digesters has potential to reduce the risks of encountering these pathogens if operated properly. However, risks could be increased due to the person handling the materials undergoing increased direct contact with these pathogens, the digester amplifying the growth of certain pathogens, or the processed material from the digester being used as a fertiliser for agricultural crops where it would not otherwise have been used. The risks from these pathogens can be mitigated by developing a toolkit that includes safe operating instructions. Microbiological data should be generated for the pathogens or indicator organisms to determine the extent to which the levels change during the anaerobic digestion process. Advice on the application of material processed for agricultural use should also be provided.

There is currently only limited data on pathogen losses to the wider environment in SSA. Most organisms appear to show a significant decrease in organism counts (~1-4-log reduction in mesophillic systems) on anaerobic digestion, although in one study, some pathogens (*Listeria and Salmonella*) appeared to increase significantly (3-log increase). Factors that need further investigation include the impact of digester design, influent waste characteristics, temperature-time dependent decay, the generation of volatile fatty acids which can be toxic to some pathogens, sludge or hydraulic retention times, liquid and/or solid usage, and the robustness of treatment performance under changing inputs.

2.4.4. Household air quality

Humans spend much of their time in indoor environments. Three billion people globally are exposed to smoke from burning biomass fuels such as wood, charcoal and dried cow dung in their homes. Exposure to this smoke is linked to pneumonia, lung cancer, and chronic lung diseases. It is estimated that this leads to about 1.2 million premature deaths annually and because much of the disease burden is borne by those under 5 years of age the total health burden is about 3% of total healthy years lost globally - a figure comparable to the effects of malaria..

Often houses in Sub-Saharan Africa use a simple stove with no flue or ventilation, resulting in an accumulation of indoor air pollutants during cooking. Indoor air pollutants include fine particulate matter (‘smoke’), composed of fine particulates less than 2.5μm (PM2.5), coarser particulates of 10μm (PM10), carbon monoxide (CO), airborne endotoxins from gram negative bacteria, and other chemicals (polycyclic aromatic hydrocarbons (PAHs), arsenic, aldeyhdes, nitric oxides, benzene, and sulphur dioxide). PM2.5 is composed of small particles that are inhaled into the deep areas of the lung.

There is extensive epidemiological evidence that links PM2.5 air pollution to respiratory and cardiovascular health effects (for example, Pope et al., 2009), with increased risk of developing acute lower respiratory tract infections, chronic obstructive pulmonary disease, lung cancer, asthma, cataracts and tuberculosis due to exposure (Po et al, 2011). The World Health Organisation estimated that indoor smoke from solid fuels is the 10^{th} highest contributing factor to the global levels of premature death (Smith et al, 2005), 76% of the global exposure to particulate matter pollution occurring as indoor air pollution in developing countries (Smith, 1993). Ezzati and Kammen (2001) showed a strong relationship between exposure to particulates and acute respiratory infections in Kenya.

Studies of different types of biomass smoke in homes in India, Nepal and Malawi (Fullerton et al., 2009) showed that fine particulate concentrations peaked during cooking periods, decreasing in the order cow dung / wood in India (820 $\mu g/m^3$ 24h average), wood in Nepal (792 $\mu g/m^3$ 24h average), charcoal / wood in Malawi (226 $\mu g/m^3$ 24h average), and LPG in Nepal (67 $\mu g/m^3$ 24h average). The factors that determine particulate concentrations are cooking location, fuel type and house type. Peak exposures can be as high as 20,000 $\mu g/m^3$ and personal exposures may be even higher. Dried animal dung and crop residues give higher particulate and endotoxin exposures than wood, charcoal or LPG. Carbon monoxide levels showed similar peaks in concentrations at cooking times, with charcoal resulting in the highest exposures to CO. Work on LPG shows ten-fold or more reduction in particulate exposure. Similar results would be expected in homes using biogas digesters.

Potential interventions to reduce exposure to indoor air pollution include reducing the source of pollution (improved cooking devices, alternative fuel-cooker combinations, and reduced need for fire), improving ventilation and placement of the stove in the living environment, and reducing exposure to smoke by drying fuel, using pot lids, maintaining stoves and keeping children away from the smoke. One of the primary benefits of changing from burning dung, crop residues or fuel wood to biogas is likely to be reduced concentrations of indoor air pollutants. The short and long term heath improvements need to be quantified and used to educate householders of the potential health benefits of biogas, demonstrating the reduction of smoke in the home.

Particulates are best measured using a pumped sample, but this causes problems with battery life and noise. Gravimetric methods, which collect the particulates on a filter are effective but require careful handling and transport/storage of filters. Photometric meters are perhaps the best method of quantifying particulate levels, but these require expensive equipment. As an alternative, carbon monoxide can be measured as a surrogate for particulate matter. This uses small diffusive Drager tubes, which are cheap and can be linked to real-time logging instruments. However, in some instances the correlation between CO and particulates may be poor.

2.5. Extension Issues

(Vianney Tumwesige, Emma Casson, Grant Davidson, Jo Smith)

Biomass accounts for 74% of the total energy consumption in SSA, compared to only 37% in Asia and 25% in Latin America (Davidson, 1992). People living in SSA lack access to clean, affordable, reliable, safe, and environmentally-safe energy and rely on solid biomass to meet their basic needs for cooking (Brown, 2006).This is a core dimension of poverty and a severe constraint on development.

In assessing the digester design and size, 4 factors interact to determine the optimum installation (Figure 2.5). The amount and nature of feedstock available on site is the first driving factor; if the installation requires more feedstock every day than is available to the household, the digester will not perform effectively. The energy demand is the second factor determining the size of the digester; there is no value in installing a biogas digester that produces more biogas than the household needs. This would mean wasted time and labour in feeding the digester and the need to vent excess biogas. The cost of the system is a strong determinant; a different digester design may provide a better supply of biogas, but if the householder cannot afford the proposed system, it is unsuitable for their purposes. Finally, an issue that is often overlooked is the space available for the installation; if the household is in an urban setting, there may be insufficient space for a permanent underground structure; if the house is rented, the householder may prefer a system that can be moved if the rent expires.

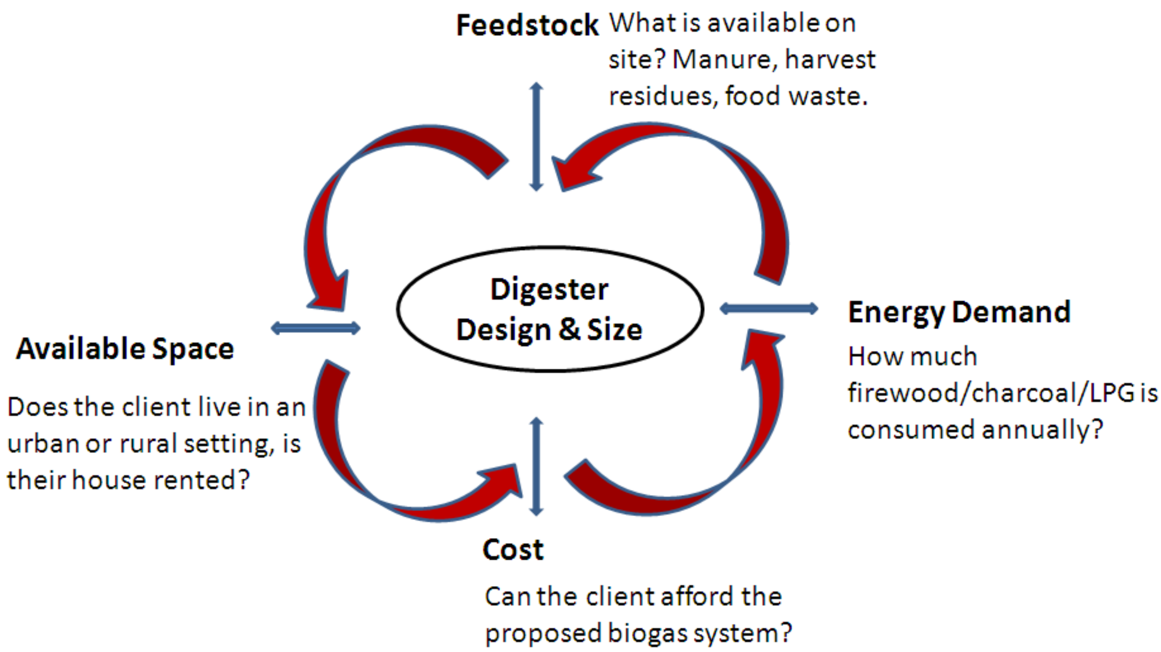

Figure 2.5. Factors that determine the optimum design and size of biogas digester. (Tumwesige & Casson, pers.comm. 2011)

Reasons for failure of biogas installations are technology and skill related; poor construction techniques and inadequate maintenance and repairs lead to failure and short life of the digester. Inadequate preparation and follow-up services after installation are a main cause of this. Householders should be given training sessions to increase their understanding of potential problems and to develop a relationship with the organisation supplying the digester, so that they are able to quickly obtain help when needed. Participatory planning should be used, accounting for the expected future status of the family in determining the best way to integrate the biogas digester into their particular farming system. When work starts on the digester, planned activities should be completed on time.

To improve the service, the outputs and outcomes of the installation should be thoroughly documented, monitored and evaluated. Even with thorough preparation and follow-up, digesters can sometimes fail due to unforeseen changes in the family circumstances, such as reduction in the number of animals kept, resulting in an inadequate supply of feedstock to provide sufficient gas for the family. This might suggest the need for a digester design that allows the capacity to be easily increased or reduced to match the current circumstances of the family. Ideally the food supply for the animals should be grown on the farm, so ensuring the supply of feed for the animals and so also the supply of manure is maintained even if the financial circumstances of the family are poor.

A decision support system is needed that will integrate the engineering, microbiological, socio-economic, environmental and extension issues to provide a rational basis for choosing to install a biogas digester, selecting an appropriate design of digester, and providing the concept and detailed design for the installation. This should include an analysis of the whole farm system, integrating the digester with the other enterprises employed on the farm. Equations describing the flows of carbon, nutrients, water, finance and labour through the system should be presented in a spreadsheet as well as being laid out in a freely available manual, allowing equations to be adapted to suit the needs of a particular site. These calculations should allow potential costs and savings associated with installing a biogas digester to be more fully understood and optimised to provide maximum benefit to the householder. Seven key questions should be addressed: what is the household energy requirement; how much organic waste does the household produce; how much biogas is produced; what reduction in deforestation does the change from the previously used fuel to biogas represent, expressed as the reduced area of deforestation and the increased carbon stock in trees; what is the value of the digested material as an organic fertiliser; what is the potential improvement in air quality through reduced use of cook-stoves; and how much does use of a biogas digester improve water quality.

3. Small-scale biogas digesters in Uganda

(Johnny Mugisha)

3.1. Socio-cultural acceptability of using biogas fuel and digested organic waste in Uganda

(Jane Bella Magombe)

Jane Bella Magombe is a farmer and owner of a biogas digester, which she has been using since 1995. She comes from an organized co-operative society of women farmers, known as the Bugusege Women's Livestock Co-operative Society. This group has been supported by Heifer International since 1990 and so far 530 households own heifers on zero grazing practice. She comes from a heavily populated mountainous area of Eastern Uganda, and so most farmers own small plots of land of about ½ hectare to 3 hectares on which they live, keep their cows and other animals, and practice agriculture. The first biogas digester was constructed for a farmer as a pilot project in 1993. This was successful, using cow-dung as the feedstock. In 1995, six farmers volunteered to have fixed dome biogas digesters constructed in their homes. Acceptance and adoption from others in the community has been slow. Last year the farmers were given another chance to help marketing biogas digesters. The response has been slow due to issues of tradition, religion, culture and technology.

Tradition - In Jane's culture, the cow is highly regarded as a source of wealth and social status. In earlier times, the more cows a farmer had, the wealthier he was considered to be and the more he was respected. A local belief is that to qualify to marry, a farmer must own sufficient cows, and this is judged from the number of droppings in his compound. The more cows the farmer had, the more dung would be available for various functions. Cow dung is widely accepted, being used as cement, for plastering the houses, reinforcing the granaries and straw tray grain winnowers. However, even though dung is regarded as a necessary asset in homes, it is never handled by men. The compound and kraal cleaning, the plastering of houses and granaries, the reinforcement of straw tray grain winnowers is exclusively done by women. Therefore, the target market for a biogas digester is the woman of the household.

Religion / Culture - In the traditional healing practices, cow dung was used to smear on the head, chest, arms and legs of the sick to invoke the spirits to heal the person. In Christian beliefs, churches are still being plastered by cow dung in many areas. So cow dung is in no way shunned or regarded as Taboo. However, people from some religions, such as Islam, will not see or touch pigs, eat pork, or even eat a meal in a home where pigs are kept. Whereas handling of cow dung is a very normal and acceptable practice, handling pig dung has not been well accepted even by those who keep pigs. Production of gas for cooking from dung causes many mixed feelings. Many people think the food will be contaminated, and in the case of Muslims, cooking with pig dung gas is not acceptable. Many people cannot imagine that a mere gas will provide enough fuel for cooking or lighting. The more recent technology using human waste in the digester has caused cultural and social challenges. There is a general feeling that it is not right to get gas from human waste and cook with it, even if it the human waste is not recognizable in the slurry. The acceptability, therefore, of the digester is higher for those that are not connected to the toilet for humans.

Technological issues - In Jane's community, people keep cows under semi or zero grazing practices because of scarcity of open grazing land. This makes it easy for farmers to collect dung and urine which could be fed into the digester. For those who adopt the technology, mixing cow dung, urine and water to feed the digester therefore does not pose a social or cultural problem because handling dung even with unprotected hands is quite normal. However, the biggest challenge is associated with the use of semi-permanent housing. People have little or no experience with use of cement and bricks, and it does not make sense to incur huge expenses to construct a digester underground that is more permanent than their house.

In conclusion, the slow adoption of the bio-gas digester and organic waste is partly due to:

1. Cultural hindrances, especially for men to touch cow dung, meaning there may be a lack of support for women to construct digesters.

2. Cultural / religious beliefs also act as a great hindrance for quick adoption of the biogas digesters.

3. The use of cement in construction of the biogas digester, when it is often not used in the construction of houses.

4. Lack of knowledge about other alternative materials that can be used in biogas production.

3.2. Measures to encourage uptake of biogas digesters in Uganda

(Emma Casson, Patience Turyareeba, Grant Davidson, William Ssendagire, Sylvia Nakami)

Measures to encourage uptake of biogas digesters include demonstration of the financial return and payback time for the investment in the digester. These can use estimates of the available feedstock, and the fuel produced from the feedstock to account for the cost of the fuel replaced by biogas. This allows the time required for the savings in fuel to pay back the cost of the digester to be estimated. Further measures that could encourage uptake include respect for the skills of masons, translated into fair and full payment and recognition of the multiple functions and opportunities presented by biogas units.

3.2.1. The Multi stakeholder Approach in Biogas Technology Dissemination: The African Biogas Partnership Programme (Hivos, HEIFER International, SNV)

The African Biogas Partnership Programme (ABPP) is being implemented in six African countries through a "multi-stakeholder sector development approach". This is a systemic approach to developing biogas programmes inspired by SNV experience in Asia. Thirty million Euros has been committed by the Directorate General for International Cooperation (DGIS) of the Ministry of Foreign Affairs for the Netherlands Government to finance 70,000 digesters, knowledge management, fund management and SNV technical assistance. This is a five year programme, running from 2009 to 2013. The target countries are Burkina Faso, Senegal, (West Africa) Ethiopia, Uganda, Kenya, Tanzania (Eastern Africa). African ownership of the programme is important; this is achieved through stakeholders meetings, national steering committees, and national implementing agencies, managing the programme in each country. The programme uses a sector approach; this aims to create and further develop a biogas sector, including masons, financial service providers, rural extension agencies and training institutions, and involves government, the private sector, NGOs and farmers organisations. Domestic digesters for cooking and lighting are paid for by the end-user but with credit provisions and a subsidy. Quality standards and a guarantee system are included to ensure confidence in the investment. The scheme also involves sanitation promotion and bio-slurry use.

The programme is overseen in the Netherlands by a programme committee involving DGIS, SNV, and Hivos. At supra-national level, the Hivos fund management and coordination office for the 6 countries is based in Nairobi with a small team. SNV are responsible for knowledge management and some applied research. At national level, in each country there is a Biogas Steering Committee (in Uganda, chaired by the Ministry of Energy and Mineral Development), and a National Implementing Agency (in Uganda, Heifer International). SNV provide technical assistance in Uganda.

The goal of the Ugandan domestic biogas programme is to improve the livelihoods of rural and peri-urban farmers through use of the market and non-market benefits of domestic biogas. A sustainable biogas sector depends on balanced interaction of consumers, providers and regulators. The programme temporary interface aims at creating and improving the relations between the regulatory body, providers and consumers. The objectives are to (1) develop a commercially viable market oriented biogas industry (2) strengthen institutions for development of the biogas sector (3) construct 12,000 quality biogas digesters (4) ensure continued operation of biogas digesters (5) maximize all benefits associated with gender, environment, employment, bio-slurry use, food security etc and (6) utilize carbon revenues from greenhouse gas emission reduction from biogas digesters for financial sustainability.

The Ugandan programme has selected modified CAMARTEC (fixed dome) digesters, model size 6, 9 and $12m^3$. This design was selected because it requires low maintenance; uses underground construction, saving space and guarding against temperature fluctuations; has a higher product life expectancy than many other designs; does not have moving or rusting parts; and provides opportunities for skilled local employment. The Uganda Domestic Biogas Program (UDBP) has trained masons (181, including 9 female) and instructors (17 including 2 female); trained and equipped promoters with "promoters kit" (92 including 33 female); and trained users (over 270) in operation and maintenance of the bio-digester and use of bio-slurry. To date, a total of 626 biogas digesters have been constructed at households each receiving a subsidy of ~ 650,000 UGX, ensuring that each household builds a compost pit. Over 21 households have also constructed bio-toilets. The cost of a $6m^3$ digester has been reduced from 2.1m UGX (2009) to 1.5m UGX (2010) by reducing overheads (supervisor's fees, reduction in construction company fees etc). Further cost reduction to ~ 1m is anticipated through introduction of Interlocking Stabilized Soil Blocks (ISSB). UDBP has been working with a number of service providers, both private sector (~10) and CBOs (~7), and plan to work with implementing partners (3). In addition, 2 MFIs and 2 SACCO have been attracted to pilot biogas loans among farmers.

There are a number of different perceptions as to the approach that should be taken in "multi-stakeholder sector development". High upfront costs of biogas digesters (~ 1.5m to 2.1m UGX) may inhibit development, especially because credit access is a problem, with only a few credit service providers willing to take the risks associated with this product. Many appliances are inefficient, with few producers or importers. Drop-out rates for trained masons is high, with only ~ 60% of the masons trained remaining active in 2010. There is a need to focus on the ultimate goal of having a commercially viable sector. This vision should be shared by all stakeholders. Regulation, consumer demand and the supply of the market all need development, and this could perhaps be achieved by allowing the private sector take the lead and supporting the development of an enabling environment.

3.2.2. Developing partnerships

Developing partnerships to encourage uptake of a new technology begins at the proposal stage. It includes collaborators from different sectors, and each brings in existing networks and different approaches to partnership development and networking.

3.2.3. Rural development opportunities

Rural development opportunities associated with biogas digesters include self-sufficiency in energy, a better living environment, increased investment in livestock, employment opportunities, increased household income, improved position of women in communities, reduction of the family workload, and training opportunities. Self-sufficiency in energy is achieved through changing attitudes to traditional energy use in rural areas, allowing less dependence on non-renewable fuels, firewood, charcoal, and paraffin, and more reliance on biogas. A better living environment results from improved household air quality, improved sanitation, and sustainable organic waste management, resulting in reduced in flies and odours. Encouraging poorer households to invest in livestock for energy production can also provide benefits from livestock products, such as milk and meat. Employment opportunities in the biogas sector are created, especially for young people, through the development of business opportunities in the construction and marketing of biogas plants. Household income may be increased through increased crop productivity associated with the use of the bio-slurry as an organic fertiliser, or by introducing additional sources of income, such as fishponds fed by bio-slurry. The position of women may be strengthened in communities, by the biogas programme increasing access for women to credit and savings, ownership of land and cattle, leadership and empowerment. The family workload may be reduced by decreasing the amount of time spent collecting and carrying heavy loads of fuel wood and charcoal, so allowing more time for education, training opportunities and work. Biogas digesters support government agricultural drives for rural transformation in developing nations, for example the "Plan for Modernization of Agriculture" (PMA) in Uganda, and "Kilimo Kwanza" in Tanzania. Key challenges include difficulty of financing the installation of the digester, poor operation and maintenance, and negative cultural and religious attitude to the use of digesters. These can be addressed by cost-sharing (UDBP provides a subsidy), regular user training and monitoring, and promotion and marketing strategies.

3.2.4. Meeting initial investment costs for digesters – the need for micro-financing

Financing is a very important part of the process of dissemination of domestic biogas plants. Promotion of biogas leads to increased awareness, which leads to evaluation and decision making and eventually to adoption. After adoption, financing is required before construction and installation can take place. Investment costs and accessible credit schemes play a vital role in motivating a potential farmer to install a biogas plant.

The CAMARTEC design being promoted in Uganda is an expensive design as it is both labour and material intensive. SNV estimates the current cost of construction in Uganda of a digester with volume $6m^3$ to be 1,380,000 UGX (\$604 = \$101 / m^3); $9m^3$ = 1,800,000 UGX (\$788 = \$88 / m^3); and $12m^3$ = 2,000,000 UGX (\$876 = \$73 / m^3).This is significantly less than costs estimated by the Ugandan

Carbon Bureau (8m^3 = 4,000,000 UGX ($1752 = $219 / m^3); and 12m^3 = 4,450,000 UGX ($1949 = $307 / m^3)).

Over 100 flexible balloon digesters are estimated to have been installed in different parts of Uganda. The estimated cost of a digester is much lower, 340,000 UGX ($200) (volume unknown). They have the disadvantage of low gas pressures and correspondingly slow cooking times or insufficient brightness of lights. They also suffer from frequent clogging at both inlet and outlet pipes points, and the polythene bags are found to be very fragile, often lasting for only 2-3 years, with some being damaged within 6 months.

Floating drum digesters can be smaller and more convenient for household use than a fixed dome digester, but are more expensive on a cost / volume basis due to the cost of the gas production and gas collection units. A 1.5m^3 floating drum digester was constructed with support from the Ugandan Carbon Bureau at a total cost of 980,000 UGX ($429 = $286 / m^3) and a 2m^3 digester was constructed at a cost of 1,400,000 UGX ($613 = $307 / m^3). The investment and maintenance costs for a floating drum digester are comparatively high, so few of these digesters have been installed in Uganda.

The average number of cows owned by a dairy farmer in Uganda is 2 heifers. This number of cows will produce sufficient feedstock for a 6m^3 digester. Assuming milk production is for 30 days per month for 7 months in the year at an average rate of 10 litres / day, and given a milk price of 600 UGX per litre, a typical dairy farmer will earn 2,520,000 UGX from his/her cows each year. To buy a 6m^3 fixed dome digester at 1,380,000 UGX would therefore require 6.5 months income to be saved. This emphasises the need for a basic loan to facilitate the adoption of biogas.

Finance institutions target mainly economically active people and viable institutions. Although the micro-finance sector is well developed in Uganda, availability of credit for renewable energy technologies is still limited. The micro-financing institutions charge high interest rates with short and inflexible repayment periods which keep biogas plants beyond the reach of many poor farming households. Illiteracy, especially amongst women, concentration of micro-financing institutions in urban areas, inadequate collateral, inadequate monthly cash flow, and variable loan terms all make micro-financing difficult for poor rural farmers. Micro-financing institutions need to be made aware of the technology and its attractiveness as a loan product. Reduced household fuel costs for cooking will realise immediate financial benefits, providing about 75% of the energy needs, allowing households cooking with biogas to save $83-$120 per year. However, note that even without interest, this would mean a payback time of 5 - 7 years.

Micro-financing institutions need to have access to funds at suitable costs to lend to this sector. One of the reasons for high interest rates for borrowers is the high costs to the micro-financing institutions of accessing their own funds. On average, micro-financers in Uganda are paying 12% annual interest for their funds. Therefore it is essential to establish a revolving wholesale biogas credit fund to provide wholesale loans to micro-financers at low interest rates. These micro-financers can then lend to households to finance biogas plant construction at a reasonable rate. Micro-finance institutions lack capability and confidence in financing biogas, so capacity building is essential, focussing on promoting biogas among their users, assessing the potential risks when financing biogas, linking with private companies and better management of wholesale loans.

Credit could also increase accessibility to biogas technology for the farmers. Credit will enhance outreach and product diversification of micro-financing institutions, assisting in mass biogas dissemination, and ensuring good quality digesters are installed since the farmer is able purchase all necessary equipment. However, questions remain as to the effectiveness of credit, the impact on the poor and the precise nature of suitable terms and conditions for credit.

Community based savings and credit cooperatives would be better placed to provide loans on softer terms with lower interest rates, longer repayment periods (2-3 years) and flexible repayment terms to fit the seasonality of farmer incomes. Cooperatives can operate at smaller rates than commercial micro-financing institution since they know their prospective clients and their transaction costs are lower. In addition to credit cooperatives, diary cooperatives can also be the appropriate institution to provide financing for biogas plants. Dairy farmers have regular income and can pay their loans. It will be relatively easy for the dairy cooperative to collect the instalment payments as they access farmers' income from selling milk. This cooperative can simply deduct the instalment amount while paying their payments to the farmers. Successful implementation of credit scheme through cooperatives will prove that biogas can be an attractive loan product and will likely attract commercial micro-financing institutions into this sector, with increased awareness and capacity. Lower interest rates established by cooperatives will also force the larger micro-financers to offer competitive rates.

3.3. Visit to biogas digesters in vicinity of Kampala

(Emma Casson & Vianney Tumwesige)

Three digesters were visited: a small fixed dome digester at a small pig-farm in Buwambo (figure A.3); a small floating drum installation in an urban area in Kajansi (figure 3.1); and a larger fixed dome digester at Nsambya Babies Home in Kampala (figure 3.2). Issues raised during the field visits included the need to demonstrate improvement in crop yields with application of digested slurry compared to the yields obtained using previous practices; the cost of the different designs of digesters and accessibility to the rural / urban poor; and the need for on-site demonstration of the improvement in household air quality achieved through use of biogas in the place of fuel wood (firewood or charcoal). The possible decrease in the amount of carbon applied to the soils was highlighted as an issue, where some designs of digesters allow organic solids to compress at the bottom of the digester, and so there is the potential for carbon sequestration in the soil to actually be *reduced* by the use of biogas digesters. The additional need to vent methane from some designs of digesters to avoid build up of pressure and possible explosion could potentially *increase* the release of potent greenhouse gases to the atmosphere, so increasing global warming potential rather than reducing it. These factors need to be quantified. The use of human wastes as digester feedstocks was discussed. In many societies, this would be considered a dirty practice, and might inhibit the uptake of biogas digesters. Initially, it is expected that human waste will not form a key part of the biogas programme, although it is important that this should be included in the long term due to the potential benefits to sanitation.

Figure 3.1. Floating drum digester in Kajansi

Figure 3.2. Fixed dome digester at Nsambya Babies Home in Kampala

Comments from the field visits also highlighted the need to regularly reassess suitability of design and adopt improvements that are being developed on biogas digesters outside of Uganda. These included; 1) making a more user friendly water trap to release water vapour from the pipeline 2) streamlining the feeding process, so that no handling of manure and manual mixing is needed and 3) optimising gas combustion in the stove.

4. Small-scale biogas digesters in Ethiopia

(Assefa Abegaz)

4.1. The status of Biogas technology in Ethiopia

(Dereje Yilma)

The Ministry of Energy and Water includes 28 directorates (departments). Biogas is covered by two of these:

(1) the Alternative Energy Technical Dissemination and Promotion Directorate (AETDPD) covering the household energy efficiency programme through improved biomass fuel efficient stoves (Mirt, Gonzye, Lakech), the Rural Electrification (alternate energy) Fund (micro, hydro., diesel generators, solar and wind); and the National Biogas Programme;

(2) the Alternative Energy Design and Development Directorate (AEDDD) including research and development of new and improved technology – eg. wood fired stoves, agricultural residue biomass, small hydro, solar and wind energy facilities, workshop and laboratories.

Biogas was first introduced in Ethiopia in to Ambo Agricultural College in 1957/58 in order to generate the energy required for welding agricultural tools and other equipment (Amera, 2010). During the 1960s, biogas units were introduced in Asmara, Eritrea, then part of Ethiopia. In the 1970s under an FAO Project to promote biogas, 2 'pilot' biogas units, one with a farmer near Debre Zeit that is still functioning, and another with a school near Kobo in Wollo were build. Dr Tewolde Berhan G/Egziabher, then Dean of the Faculty of Science in Addis Ababa University, was the project leader for the FAO Project. In the past two and half decades around 1000 plants (size ranging 2.5 – 200 m^3) have been built for households, communities and institutions by nine different GOs &NGOs. Today, 40% of the constructed biogas plants are non-operational. A range of different models of biogas digesters have been used: Indian floating drum, Chinese fixed dome, Camar Tech, Deenbandhu, Polyethylene (plastic bag) and LUPO fixed dome type. There are a number of different reasons for failures including the centralized project approach (resulting in poor communication with householders), poor operational capacity of the householder family, inconsistent design (resulting in inadequate support for the range of designs used), lack of technical follow up, poor site selection, change of ownership, and poor performance of the appliances.

The National Biogas Programme for Ethiopia has therefore devised a new approach, formulated by the former EREDPC and SNV Ethiopia in 2006. Lead institutions are the Ministry of Water and Energy, Regional Energy Bureaus, and Wereda (District) Energy Desks. Operational management is by the National and Regional Coordinating units, other GOs and NGO stakeholders through the federal and regional energy offices. The approach uses a standardised design, participatory planning to produce a commercially viable system, aims to create local jobs, uses proven technology and attempts to build capacity in technical ability. It is currently being implemented in four regions as a pilot (Amhara, Tigray, Oromia and SNNPRS). The potential for biogas installations is more than 1.1 million potential inthese four regions alone. 14,000 plants are planned to be installed over five years (2009 – 2013), of which 3,500 will be in these four regions. 50% of the plants are expected to include a toilet attachment. The aim is to ensure continued operation of at least 95% biogas plants and so maximize the potential benefits of biogas.

The biogas digesters installed are the Sinidu model GGC 2047 (figure 4.1) and range in size from 4 to 10 m^3. The biogas is mostly used for house hold lighting and cooking, and the bioslurry is used as a fertilizer. The life time of the biogas digesters is expected to be 20 to 25yrs. Clear site selection criteria have been devised n order to maximise the success rate of installed digesters. A multi-stakeholder approach is used (including ISD, Forum for Environment (FfE), STVC, MFIs, SNV, AJQMplc, GOs and NGOs). Capacity for installing biogas digesters is developed through different levels of training.

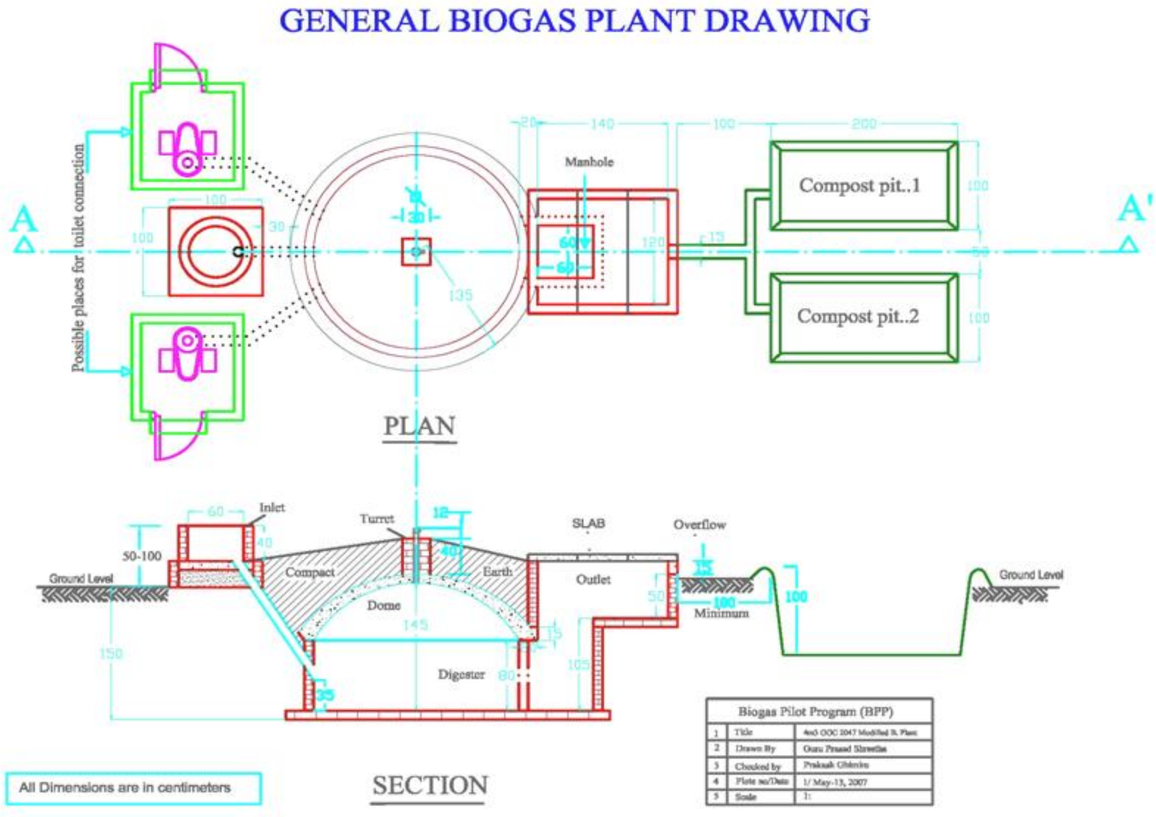

Figure 4.1. General biogas plant drawing for the Sinidu model GGC 2047

The total program investment is €16.6 million: contributions (for each installation) are 4% from the federal government, 3% from regional governments, 43% from each biogas user, 39% from donors (The Netherlands Government through HIVOS), and 11% and technical assistance from SNV Ethiopia. The Federal Government (MoFED, MoWE and AEDPD) lead the program activities in line with the national policy and strategy. This includes overall planning, impact monitoring, fund management, research and development, quality assurance, and securing a financial contribution to provide a constant cost for the digesters. The National Biogas Program for Ethiopia (NBPE) Coordination Unit supports regional biogas coordination units, funds and contributes to constant cost channelling, standardises quality assurance mechanisms, coordinates research and development, is responsible for promotion and marketing, provides accreditation of biogas companies, strengthens and coordinates partner organisations, and leads training and slurry extension programs. SNV Ethiopia provides experience from more than 35 country programmes in Africa, Latin America, Asia and Eastern Europe, and is responsible for fund raising activities, local capacity building in technical ability, organisation and appliance production, and provides technical support to Ministry of Water and Energy and the National Biogas Programme. Biogas owners are responsible for the supply of local construction materials and labour (~1117 Birr or $66), the integration of the technology into their daily routine, ensuring sufficient and regular gas production, adherence to operation and maintenance instructions (as stipulated in an owner's manual and information disseminated at user training). Regional Energy Bureaus coordinate regionally based GOs, NGOs, MFIs and savings and credit cooperatives, the private sector, and construction cooperatives, and are responsible for promotion and quality assurance. The regional biogas coordination units provide coordination at the regional level, quality control, promotion and slurry extension work, and assist private sector development. The programme has now been fully formulated and lead organisations have been selected. The programme contracts have been signed, national and regional coordination units established, and the demonstration phase has been implemented. Manuals, guidelines, standards and formats, slurry extension and quality assurance schemes are being developed. Appliances and fittings for biogas lamps have been manufactured. Exchange visits, farmers' field days, knowledge network and planning meetings have been carried out. A number of different surveys and studies have been conducted to support the programme, and research and development to improve appliances has been initiated (biogas injera stove, biogas lamp, stove efficiency improvement). Currently, 1300 biogas digesters have been constructed in 42 weredas (districts). Despite this progress, the rate of construction has been lower than planned due to delayed start up of the programme; late credit facilitation; price rises in cement; high investment required for construction; initial lack of widespread promotion; lack of awareness within the rural population, stakeholders and government offices; and limited supply of appliances and fittings.

4.2. Biogas for poverty reduction and climate change mitigation: The case of Ethiopia

(Zenebe Gebreegziabher)

Over the last 2 decades, ~1.4 billion people have survived on less than $1.25 / day, and 70% of the world's poor live in rural areas (IFAD, 2010). Declining agricultural productivity, due to deteriorating natural resources, have contributed to this rural poverty. Nitrogen and phosphorus deficiencies are the major biophysical constraints to agricultural production in Africa. Because of scarcity of fuel wood, rural people have switched to burning animal dung and crop residues for fuel; this has resulted in progressive land degradation, due to loss of organic matter and nutrient depletion. Biogas provides an alternative source of energy, and so allows farmers to start to use organic wastes again to replace organic matter and reduce nutrient depletion.

Biogas was first introduced to Ethiopia in the 1970s; most digesters were installed at demonstration centres. However, biogas digesters are still not widely used. The Ethiopian government and SNV Ethiopia have embarked on an ambitious plan to construct around one million biogas plants in Ethiopia (figure 4.2). The Program plans to construct 14,000 plants in the period 2010 to 2013, in the Amhara, SNNPRS, Oromiya, and Tigray regions. According to SNV, 100 biogas plants were constructed during the demonstration phase in 2008 and 11 others were constructed within the first half of 2009. The cost of construction was 11,000 Birr (~$660 or Euro 720) for a 6 m^3 digester, of which 33-40% of the costs were provided by the program.

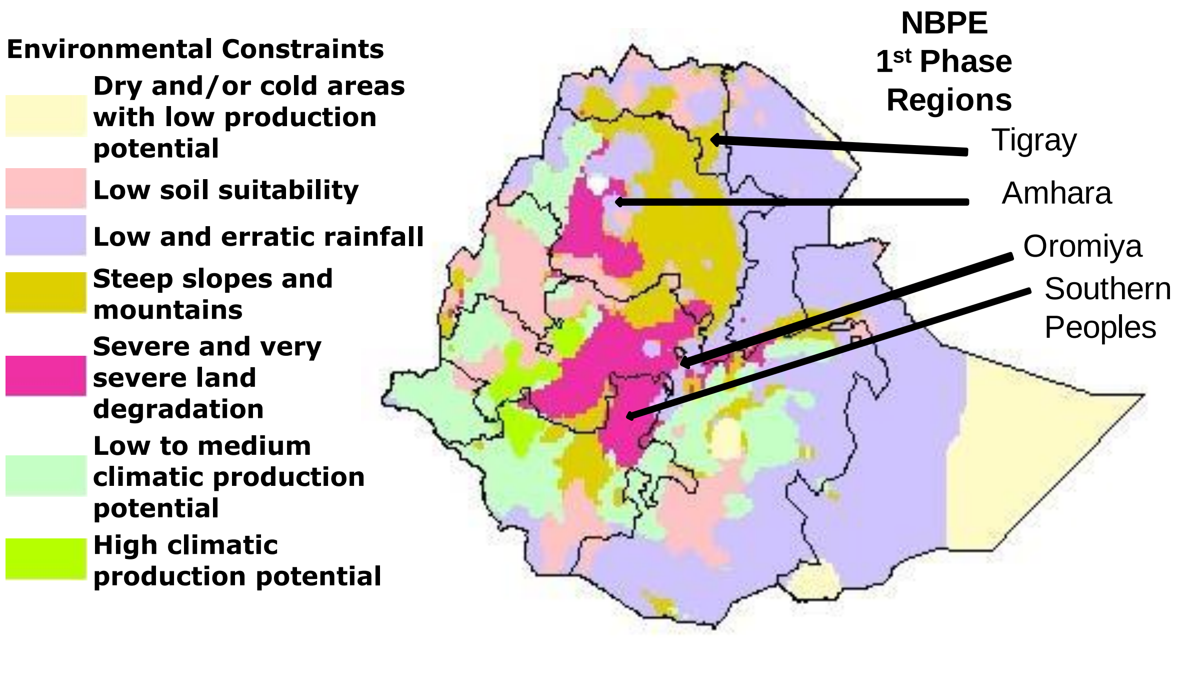

Figure 4.2. First phase introduction of biogas plants in Ethiopia

What potential improvements to overcome rural poverty and improve the environment can be achieved by installation of biogas digesters? Three alternative levels of productivity improvements were assumed due to use of the bioslurry produced by the digester: 11, 16 and 20% yield increase (some evidence suggests yield improvements could be as much as 100%; Edwards, 2008). A cross-section of 200 rural households was considered in the Enderta and Hintalo-Wajerat districts of Tigrai, northern Ethiopia, using crop production for 2002 as a baseline. Three crops were considered; teff, wheat and barley (this includes ~80 % of the arable land).This represents an increase in yield of 120 – 218 kg / year / household, representing a revenue increase of 169 – 306 Birr / year / household ($10-$18 / year / household). This represents a change in poverty gap index of 0.064 – 0.097 and a change in poverty severity index of 0.054 – 0.084. By substitution for kerosene (average 13.3 lt/household) and cattle dung cake as fuels (meaning less requirement for fertilisers), this represents an average reduction in global warming potential of 9.7 t CO_{2e} / year. Given a current carbon price of US $9 / t CO_{2e}, this is equivalent to carbon credits of US $87 / year if linked to the carbon markets.

Injera baking is a major use of cooking fuel in Ethiopia, accounting for 60% of household fuel consumption, both in urban and rural areas. However, little attention has been given to injera baking in the design of biogas cook stoves. Innovation is needed to design an integrated biogas cook stove that includes injera baking for household and institutional applications. Although, biogas lamps can provide better illumination than many other available forms of lighting in rural areas, the lighting efficiency is generally quite low, averaging between 3% and 5%. Improvements are needed to the design of biogas lamps to improve efficiency and make them more robust. Potential for an integrated design, providing a mix of lighting by solar batteries and biogas.

4.3. Composting and slurry as fertilizer from biogas

(Sue Edwards)

The major challenges faced by the National Biogas Programme of Ethiopia include provision of an alternative source of energy and a high quality organic fertilizer (bioslurry compost) to help halt and reverse land degradation, raise crop yields and improve soil structure and water holding capacity. The programme aims to help farmers to reduce or eliminate the use of chemical fertilizer and avoid burdensome debts. Because soils are often deficient in organic matter, application of organic fertiliser can often increase yield by a greater proportion than inorganic fertiliser alone. This can help the crops to cope better with climate change, due to increased water holding capacity, reduced erosion by wind and water, and better infiltration of water. Furthermore, many authors report reduced disease and weed infestation following application of composts. Making compost from crop residues is best done at the end of the growing season when there is sufficient wet and dry biomass from weeding, cleaning/clearing paths, etc, and water is more available: i.e. there is a limited window of opportunity. With a properly functioning biogas digester, farmers can produce and use bioslurry for making compost throughout the year.

4.4. Sector development in large scale dissemination of domestic biogas

(Getachew Eshete)

Domestic energy in rural Ethiopia has a heavy reliance on biomass fuels, a relatively high domestic energy consumption (>700kg/cap/annum), and uses low levels of renewable energy or energy efficiency technologies, so the energy demand in most areas significantly exceeds supply. There is a significant energy deficiency in rural Ethiopia with an increasing cost for household energy. This results in pressure on existing resources; deforestation / desertification, internal migration to resourceful areas, loss of biodiversity, degradation of soils (large eroded areas with gullies, and reduction of soil fertility), reduction of agricultural productivity (both for cropping as well as livestock), increased health cost due to the effects of indoor air pollution, and Increasing household workloads. This results in fuel wood becoming a (commercial) luxury good, the supply in many instances being from distant areas, women and children having to travel long distances to fetch fuel-wood for household energy, and dung cakes and agricultural residues increasingly being used as commercial fuels. Biogas is one domestic fuel option that could help alleviate these problems. Sector development focuses on a specific (group of) products and bi-products, and entails a market with a supply and demand. It involves multiple stakeholders (public and private), and provides nationwide coverage, internal provision of different services, and different sectors interdependent working together.

Technical factors that determine the suitability of a household for the national biogas programme include the household already using integrated farming, and having access to over 20 kg dung per day, sufficient funds to pay for the digester, time to run the digester and access to water. Households should also have a daytime temperature of over $20^{o}C$, and materials to construct the digesters and appliances should be locally available. It is also preferable for the area to have a history of installations. The technical potential of the programme is >10.000 digesters over 5 years. The programme has been initiated in "high opportunity areas" with a high density rural population, which allows the opportunity to construct in clusters of ~ 25 installations.

Economic factors that determine suitability are sufficient active demand for the services that can be provided by the technology (ie energy demand due to scarcity and/or high prices of traditional cooking fuels); local (rural) private enterprises that are able to supply the digesters, households with cash-income or savings that are sufficient to make a down-payment on the digester (~10% of the investment); appropriate, affordable, accessible credit facilities; and assets for collateral for biogas-credit.

Social factors that determine suitability are ownership of livestock and security of land tenure; potential to improve health and sanitary conditions; traditional use of manure compatible with operation of the installation and treatment of slurry; and cooking customs compatible with use of biogas.

The rural private sector / mason enterprises should be the prime movers for biogas marketing, plant construction and after sales service. Rural extension and credit infrastructure are also needed. The programme uses an institutional set-up with an independent operational entity for programme coordination. Women's groups should also be involved during preparation for and implementation of the installation.

The government accepts a significant but limited role (programme facilitation, policy development and market regulation), but this represents a strong commitment from national government, providing a favourable policy environment (rural development, agriculture, health, sustainable energy, global warming, etc) and opportunity for programme linkages.

4.5. Visit to biogas digesters in vicinity of Debre Zeit

(Assefa Abegaz & Dereje Yilma)

The field trip visited three householders who have installed biogas digesters within the last 5 years; two rural farms and one in an urban setting.

Household 1 – Rural, male headed

The first farm was a male-headed household, with over 10 stall fed cows, and a significant area of arable land. The farmer had been selected by the coordinator of the local cluster to participate in the programme, and intimated that during the training phase he was not at all happy about participating. However, since installing his biogas digester, over 4 years ago, he has become very pleased with the results. The main reasons for this are the unforeseen advantages provided by the bioslurry, which he composts with dry organic wastes from the cattle pens to make a good compost. Previously, a high proportion of his cattle dung had been dried and used as fuel; the biogas digester has allowed him to replace cattle dung fuel with biogas for all cooking except injera. He commented that the quality of the compost had improved since he started incorporating bioslurry in the compost heap, and that the resulting organic fertilizer had significantly improved the yield of his crops.

The slurry was thoroughly mixed in a mixing chamber above the digest inlet before releasing a plug to allow the slurry to flow into the digester (figure 4.3). The mixing was started using a stick following addition of a volume of water equal to the volume of cow manure. Water was obtained from a bore-hole on the property. Any solid materials were removed by hand, and the slurry was further mixed and sorted by hand. The possible increased contact with the organic waste that this involves could represent a significant increase in risk of infections through contact with pathogens. However, dung is already used for cooking and building, so it is not clear whether increased contact results from feeding the digester. This should be considered further in the formal risk assessment. This

Figure 4.3. Mixing slurry by hand at the inlet of a biogas digester in a rural household near Debre Zeit

approach could be modified to reduce contact with the manure for instance by adding a hand operated mixer and a sieve to the top of the digester.

Following digestion, the bioslurry was allowed to flow out of the digester along channels that lead into the compost heaps. The bioslurry was first channeled into one heap, and then when the heap was full, the channel was redirected to the second heap. This allowed the heaps to be turned and aerated to ensure adequate aeration for efficient aerobic decomposition. The heaps were covered by a shelter to avoid excessive loss of nitrogen by volatilization. However, neither the compost pits or the slurry channel was lined to avoid losses by leaching. Since rainfall in Ethiopia can be heavy, this could be a significant source of loss of both nutrients and pathogens to the wider environment. Furthermore, the channels were relatively shallow (figure 4.4), and could be susceptible to overflow losses during heavy rains. This could be reduced by covering the channels during rainstorms. Lining pits and channels by either clay or cement would be a better solution to leaching, but would require significant effort so may not be considered worthwhile.

Figure 4.4. Shallow channel taking biogas digester outflow to compost heaps at a rural household near Debre Zeit

Figure 4.5. Rose chafer bug larvae found in compost heaps near Debre Zeit

Larvae of the rose chafer bugs (figure 4.5) are present in the compost heap and help to decompose the organic material. A possible risk that requires further consideration is whether the potential increases in the numbers of these insects associated with bioslurry fed compost heaps could present an increased risk of crop damage.

The biogas was used for heating and lighting. These installations appeared to be working well, and the householder was extremely happy with the amount of gas he was obtaining. He commented that a higher yield could be obtained by mixing in human waste, but this resulted in a smaller amount of bioslurry being produced. In the interests of producing more useful compost, he preferred not to use human waste.

The farmer appeared to be extremely well informed and to have received excellent training. He was making good use of his biogas and bioslurry, and was enthusiastic and knowledgable about the processes. He had calculated the change in his economic state as a result of installing the biogas digester and perceived that the biogas digester had provided a significant economic advantage to him.

Household 2 – Rural, female headed

The second farm was also rural, but was headed by a woman. She was not using very much cattle waste in her digester, but had a dry toilet connected to the digester. She was very happy with the gas yield obtained, but admitted she was not managing her compost heaps well or making good use of the compost. The lighting provided by the gas provided good illumination, allowing her children to study after nightfall. The gas flow in the biogas stove had sufficient pressure for cooking. She used the biogas stove for all cooking except injera.

Household 3 – Urban, female headed

The third household visited was a female headed household, in an urban setting. Five cows were kept in very cramped conditions, for milk production, which was a major source of income. The householder commented that she was planning to sell 2 cows as the milk yield had dropped, and she perceived this was due to shortage of food / space. The organic waste was fed into the digester, and produced biogas for the household. However, injera cooking and lighting were supplied by cattle dung and electricity respectively. Drying of cattle dung was difficult due to the shortage of space (figure 4.6). The main problem faced was disposal of the bioslurry. This currently is stored in a 7 m deep soak-away tank, until the tank is emptied. Note that because the rate of throughput of slurry is too high, the slurry is largely undigested, and the soak-away could therefore represent a significant risk to the urban environment. In previous years, the tank has been emptied for free by the "genesis" farm, who made use of the bioslurry in producing an organic fertilizer. However, this year they have too much bioslurry, and so will no longer empty the tank. The problems of the household are clearly related to the over-crowding of the cattle. A holistic system is needed, in which the disposal of the waste is as much a part of the production system as are the cattle. Diversification of income sources might provide the opportunity for the householder to reduce the number of cattle kept, while maintaining their income. Suitable diversification options are needed, as fishponds are not an option due to space limitations and the absence of a market for fish in Ethiopia.

Figure 4.6. Drying cattle dung in cramped conditions of an urban household in Debre Zeit

Discussion

SANITATION

KY: Strong concern about sanitation. We saw children mixing the slurry by hand. 95% of diseases in SSA are infectious. Spore forming organisms can be passed across from slurry to human.

MS: It should be possible to change practices through implementation of more effective mechanical mixing systems. These systems are operational in Nepal.

LA: Need to compare the risks of using the biogas digester to the risks that were present before. There may also be an immunity effect; people who are handling the manure regularly tend to have higher immunity to potential diseases.

KY: We have a unique opportunity to incorporate the observations we have in the field to provide a thorough risk assessment. Education is needed to help people to improve their approach to dealing with manures and avoid excessive exposure.

TOOLS

JM: Tools needed: a stirrer; sieve to avoid large pieces entering digester and producing a scum; need to work on methods for people to overproduce gas and then sell gas.

JS: As an alternative to the thorough mixing and sieving, we could consider implementing digesters that are not sensitive to the size of materials incorporated (eg. BioPro, AGAMA Energy). However, need a cheaper design.

FUNCTIONING OF DIGESTERS

VT: Most of the digesters we saw were overfed – this was indicated because the bioslurry produced was largely undigested.

SE: Most digesters are too big, so people have to wait a long time before they get production. Therefore the project in Ethiopia has purposefully gone for smaller sized digesters.

KY: Perhaps the loading rate should be regulated to avoid over-feeding – provide a timetable advising on loading.

SE: Key issue is the gas production. If composting is effective in breaking down pathogens, this will be adequate.

JS: It would be better to reduce pathogens coming out of the digester as there is potential for pathogens to be washed away into the wider environment.

SE: Immunity may be increased by contact with pathogens (note this is still an unknown factor).

KY: These diseases are very prominent and we need to be careful. Odour is an indication of risk and

may also indicate small particulates being released into the air. Need to make an effort to achieve pathogen reduction in slurry leaving the digester.
AP: Indonesia's systems attempt to have lower levels of pathogens in output from the tank. A lot of attention is put on the design of the outlet, so as to make good use of the output material – separating liquids and solids for different uses.
MS: Bioslurry can be soaked up to avoid runoff loss by adding dry materials (as we saw at the first farm). This aids the composting of material.
SE: The large larvae of rose chafer bugs aid digestion, but are a pest for crops such as sorghum – breed in cattle pens. Does not attack teff, but this should be considered as a possible risk factor over the long term.
AP: In Indonesia, many types of compost are produced by slurry. The size / type of digester is adjusted to be suitable for the household. Biogas is compressed in a container and distributed.

OPTIONS FOR COMPRESSING AND DISTRIBUTING GAS
AP: Gas is compressed Use a compression unit, run by a generator.
JS: Too high tech for use in field?
SE: Gas bags can be filled using a hand operated compression unit. Need low tech solutions – tools are not very much used in Ethiopia.

COMPARISON WITH UGANDA
GD: Outflows were much more liquid in Uganda than Ethiopia.

CLUSTERING SYSTEM
GD: The clustering system doesn't seem to be providing links between householders. This would have allowed farmers to express their real feelings about the digesters, to learn from each other's experiences and to group together to solve problems (eg the disposal of bioslurry in urban setting).

COMPARISON BETWEEN URBAN AND RURAL SETTING
LN: In urban setting there were severe space limitations. No opportunity for introducing other management options (eg ponds) in the system. Disposal of slurry – a real problem in urban setting – need to pay people to dispose of it. Need one organisation to come and collect and take away to compost. This could be done through a user group.
MS: Perhaps should focus on peri-urban rather than urban area for biogas digester.
JM: In urban areas, people are using human waste treatment to produce biogas – therefore will require cattle slurry to improve gas production. Where there is a sewage system, connection of cattle slurry to the sewage system may be encouraged.
ZG: Need backing from policy systems to encourage adoption of biogas technologies – eg incentives for biogas.
SE: The dairy industry will always continue in towns because economics drive it – high supply for milk. A problem in Africa is high young population and little means to employ them. Schools are always in urban or semi-urban environments. Therefore, could link school clubs with biogas producers so slurry could be picked up by the schools, composted and used for horticultural work at the schools. Urban areas are mines on the rural environment – everything goes in, nothing goes back. The biogas programme is one way that this could happen. The number of cattle are going to remain, how we deal with the waste is the issue.
MS: Need to ensure system is working properly and adequately spaced.
GD: Three cattle well looked after might produce more milk than 5 poorly fed cattle that produce less milk.
SE: Need a socio-economic study in urban setting on biogas, dairy industry. What is happening? What is the payback? Best solutions should be built into policy.
AA: Dairy activities in urban areas generate a significant amount of income for householders. The government should organise people and help sort out a tanker to take bioslurry to rural areas. The energy produced in urban areas is not widely used for household lighting. The biogas is not appropriate to the modern household construction, which is working with electricity. Fish ponds – not recommended in this area.
RO: There is never one solution – there are appropriate solutions. What is happening to manure in the urban setting?
AA: In many households there will be space to dry manure and sell it.
SE: In some cases, bioslurry goes straight out into the road.
ZG: Think of the biogas system in a product perspective. Create market or outlet for ALL products –

including bioslurry.

DIVERSIFICATION OF

JS: Diversify – less cattle – leaving more space and invest in alternative forms of income

SE: Aquaculture is not practiced in Ethiopia – one reason is malaria – so don't put water near households. Need to solve this problem at a community level – schools linked to gardens.

KY: Why is fish not popular in Ethiopia?

AA: Fasting cultural practices avoid meat related products. Do not have experience of cooking fish.

RM: This is about accessibility.

JM: In Kenya, fish production has been encouraged by policy.

WATER

SE: Water is a real problem in Ethiopia - rainwater collection isn't widely practiced. Need to include rainwater collector as standard with any biogas digester.

5. Biogas Network and Special Issue

A key output from the work has been the establishment of an extended multidisciplinary network of researchers working in different aspects of implementing biogas digesters in SSA. The visibility of the network is facilitated by a website (http://www.vula.uct.ac.za), containing materials from the workshops and the contact details of members, and through the planned special issue of an appropriate peer-reviewed journal, planned for completion by May 2012.

The proposed titles and lead authors for the proposed publications are given below.

Environment

1. The potential of biogas digesters to improve soil carbon sequestration, soil fertility and crop production in Sub-Saharan Africa (Jo Smith)
2. Can biogas digesters help to reduce deforestation in Sub-Saharan Africa? (Madhu Subedi)
3. Holistic aspects of use of biogas for small scale farmers in Africa and Asia (Bob Orskov)

Health

4. Impacts of biogas installations on household air quality (Sean Semple)
5. Potential for pathogen reduction in anaerobic digestion and biogas generation in Sub-Saharan Africa (Lisa Avery)
6. Review of occupational diseases due to Agricultural practices in Sub-Saharan Africa (Kenneth Yongabi)

Socioeconomics

7. Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review (Jecinta Mwirigi)
8. Fuel poverty and the impact of Biogas in reducing poverty in SSA (Bedru Balana)
9. Prospects and challenges for urban versus rural application of biogas installations (Zenebe Gebreegziabher)
10. Household Energy use and energy switching in Sub-Saharan Africa: The Status of biogas energy in Uganda (Peter Walekhwa)

Engineering

11. Factors that govern stability of small scale systems and the need for effective monitoring (Linus Naik)
12. Evaluation of biogas appliances and fittings (Vianney Tumwesige)
13. Comprehensive review of reactor designs including impact on biological processes (Greg Austin)

Knowledge transfer

14. Knowledge dissemination issues associated with biogas (Grant Davidson)

6. Future work

Planned future work is included in three research proposals.

1. A proposal to phase 2 of the DFID New and Emerging Technologies Research Competition on the potential of biogas digesters to alleviate poverty in SSA (focussing on flexible balloon digesters).
2. A proposal to the AUC-HRST scheme (by J.Mugisha, Makerere University, worth 842,345 Euros) on improving the uptake of small-scale biogas digesters in rural households in Sub-Saharan Africa.
3. A proposal to the AUC-HRST scheme (by Karsten Bechtel, CREEC, Makerere University, worth 1,012,681 Euros) on improving the design of small-scale biogas digesters for use in rural households in Sub-Saharan Africa.

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Appendix A - Interdisciplinary Expert Workshop - Makerere University, Uganda, 24-28 January, 2011

Jo Smith, Greg Austin, Bob Orskov, Rethabile Melamu, Kenneth Yongabi, Johnny Mugisha, Peter Walekwha, Robin Matthews, Simon Langan, Helaina Black, Vianney Tumwesige, Emma Casson, Sean Semple, Klaus Glenk, Allison Kasozi, Harro von Blottnitz, Jecinta Mwirigi, Bedru Balana, Jane Magombe, Patience Turyareeba, Grant Davidson, William Ssendagire, Bill Farmer, Georg Zenk, Sylvia Nakami, Linus Naik

An interdisciplinary workshop was held at Makerere University, Kampala, Uganda from 24-28 January, 2011 to discuss the potential of small-scale biogas digesters to reduce poverty and improve the environment in Sub-Saharan Africa. The agenda for the workshop is given in below. Invitees were limited to key experts in different disciplines associated with implementation of biogas digesters. Only participants who were expected to have a real contribution to any further research work were invited; this was to maximize the potential for interactions and discussions as well as to minimize costs of the workshop. The 27 participants included experts from 11 organisations from 5 different countries. The full list of participants is given below.

The workshop was organized into 7 sessions. Session 1 provided an overview of the current usage of biogas digesters in Sub-Saharan Africa and elsewhere in the world. The engineering, microbiological, socio-economic, environmental and extension issues associated with using biogas digesters in Sub-Saharan Africa were summarized. Session 2 focused on potential environmental risks and benefits; deforestation, carbon sequestration and improved productivity, reduction of pathogens in the drinking water, and improved household air quality. Session 3 considered socioeconomic assessment of the potential benefits and costs of biogas digesters in Sub-Saharan Africa, presenting an economic assessment, a techno-economic feasibility study, consideration of socio-economic constraints, and a discussion of access, poverty and equity issues. In session 4, the participants moved to the field, the objectives being to stimulate discussion on the strengths and weaknesses of different digester designs, the different options for using digester slurry, the risks and benefits of installing a biogas digester, and the research needs for improving uptake of biogas digesters. Three digesters were visited: a small fixed dome digester at a small pig-farm in Buwambo; a small floating drum installation in an urban area in Kajansi; and a larger fixed dome digester at Nsambya Babies Home in Kampala. Session 5 considered the practical problems associated with implementation. We heard about a number of practical issues, including availability of materials, co-digestion of different feedstocks, and problems faced by a farmer who has been using a demonstration unit since 1998. In session 6 the focus turned to the measures needed to encourage uptake of biogas digesters, including the multi-stakeholder approach used by SNV. Overlap with experiences from a holistic agro-forestry project was presented, and rural development opportunities and micro-financing approaches used by Heifer International were considered. The sessions were dominated by lively discussions following each presentation, and during session 7 the issues raised were consolidated into plans for 3 research proposals, one to be submitted to the DFID Phase 2 of NET-RC, and the other two to be submitted to AUC-HRST.

DFID NET-RC aims to explore the most effective, safe and affordable approaches for new technologies to benefit poor people, the research needed to turn these benefits into reality, the approaches needed to build this research into development and to manage any risks, and the scale of future funding needed. Therefore this workshop has focused on the following questions:

- What is the best way to build on the emerging technology of small-scale biogas digesters for development of improved energy supplies, sanitation, air quality and recycling of carbon and nutrients in Sub-Saharan Africa?

- How can we manage the risks associated with implementation of small-scale biogas digesters in Sub-Saharan Africa?

- What longer term funding or research is needed to improve uptake of small-scale biogas digesters in Sub-Saharan Africa?

The outputs from the workshop were plans for 3 proposals to be submitted to phase 2 of DFID NET-RC and to AUC-HRST, and an initiation of an active network of experts working on biogas digesters in Sub-Saharan Africa.

Agenda

24th Jan – Session 1 - Options for the improving the design of a small-scale biogas digesters for use in Sub-Saharan Africa for development of improved energy supplies, sanitation and recycling of carbon and nutrients in Sub-Saharan Africa	
9.00	Registration & coffee
9.15	Welcome (Johnny Mugisha, University of Makerere, Uganda)
9.30	Introduction (Jo Smith, University of Aberdeen, Scotland)
9.45	Review of the advantages and disadvantages of biogas digesters currently in use in Sub-Saharan Africa (Greg Austin, Agama Biogas, South Africa)
10.30	Biogas digesters currently in use in other parts of the world (1) Vietnam; (2) Colombia – (Bob Orskov, Macaulay Land Use Research Institute, Scotland)
11.15	Break & coffee/tea
11.30	Engineering issues to be considered in selecting a biogas digester design for use in Sub-Saharan Africa (Thabi Melamu, University of Cape Town, South Africa)
12.15	Microbiological issues to be considered in selecting a biogas digester design for use in Sub-Saharan Africa – (Kenneth Yongabi, Phytobiotechnology Research Foundation, Cameroon)
13.00	Break & lunch
14.00	Socio-economic issues to be considered in selecting a biogas digester design for use in Sub-Saharan Africa – (Johnny Mugisha & Peter Walekhwa, Makerere University, Uganda)
14.45	Environmental issues to be considered in selecting a biogas digester use in Sub-Saharan Africa – (Jo Smith, Robin Matthews, Simon Langan & Helaina Black, Macaulay Land Use Research Institute & University of Aberdeen, Scotland)
15.30	Extension issues – (Emma Casson & Vianney Tumwesige, Uganda Carbon Bureau, Uganda)
16.15	Break & coffee/tea
16.30	Discussion on improved design of small-scale biogas digesters for use in Sub-Saharan Africa - What is needed to allow widespread access to & uptake of small-scale biogas digester technology? - What engineering, microbial, socio-economic and environmental research is needed? - What key activities should be included in the phase 2 DFID research proposal ? - What linked projects could be applied for and what are the potential sources of funding? OUTPUT = 1. PLAN FOR STRUCTURE OF DFID PROPOSAL; 2. LIST OF LINKED PROJECTS
18.00	Close

25th Jan – Sessions 2 & 3 - Risks and benefits associated with implementation of small-scale biogas digesters in Sub-Saharan Africa	
Session 2	Potential environmental risks and benefits
9.00	Introduction (Jo Smith, University of Aberdeen, Scotland)
9.15	Reduction in deforestation associated with logging for fuel (Robin Matthews, Macaulay land Use Research Institute, Scotland)
10.00	Carbon sequestration and improved productivity associated with soil amendments of organic materials (Jo Smith, University of Aberdeen, Scotland)
10.45	Break & coffee/tea
11.00	Fate of pathogens during biogas production and use of digested organic waste (Kenneth Yongabi, Phytobiotechnology Research Foundation, Cameroon)
11.45	Impact of biogas digesters on household air quality (Sean Semple, University of Aberdeen, Scotland)
12.30	General discussion - What are the key environmental risks & benefits associated with small-scale biogas digesters? - What research is needed to help reduce risks and maximize benefits? - How can we ensure that this research will improve access and uptake? - What environmental research is needed in the phase 2 DFID proposal and linked bids? OUTPUT – LIST OF ENVIRONMENTAL ACTIVITIES TO INCLUDE IN (1) PHASE 2 DFID PROPOSAL & (2) LINKED BIDS
13.00	Break & lunch
Session 3	Socio-economic assessment of biogas digesters in Sub-Saharan Africa - Benefits and costs
14.00	Introduction (Johnny Mugisha)
14.15	Economic assessment - benefits and costs (Klaus Glenk, SAC, Scotland)
15.00	Techno-economic feasibility of biogas from organic municipal solid waste: Lessons from Nairobi for communal scale biodigestion (Allison Kasozi & Harro von Blottnitz, University of Cape Town, South Africa)
15.45	Break & coffee/tea
16.00	Socio-economic constraints to adoption of biogas technology by farmers in Sub-Saharan Africa (Jecinta Mwirigi, Egerton University, Kenya)
16.45	Access - poverty and equity issues (Bedru Balana, Macaulay Land Use Research Institute, Scotland)
17.30	General discussion - What are the key socio-economic risks & benefits associated with small-scale biogas digesters? - What research is needed to help reduce risks and maximize benefits? - How can we ensure that this research will improve access and uptake? - What environmental research is needed in the phase 2 DFID proposal and linked bids? OUTPUT – LIST OF SOCIO-ECOMONIC ACTIVITIES TO INCLUDE IN (1) PHASE 2 DFID PROPOSAL & (2) LINKED BIDS
18.00	Close

26th Jan – Session 4 - Visit to biogas digesters in vicinity of Kampala – organisers Emma Casson & Vianney Tumwesige

Purpose of visits – to stimulate discussion on

a. the strengths and weaknesses of different digester designs
b. the different options for using digester slurry
c. the risks and benefits of installing a biogas digester
d. the research needs for improving uptake of biogas digesters

9.00	Pick up from hotel
10.00	Visit to a small fixed dome digester at Buwambo (on road to Masindi, approx. 15kms out of Kampala)
12.00	Leave for Kajansi
13.30	Visit to a floating drum digester at Kajansi (between Kampala and Entebbe)
14.00	Leave for Kampala
14.30	Lunch at Nsambya Babies' home in Kampala
15.30	Visit to a larger fixed dome digester at Nsambya Babies' home (Kampala)
16.30	Leave for Makere University
17.00	Discussion on site visits and visit to CREEC biogas unit – hosted by Karsten Bechtel (Makere University)
18.00	Close

27th Jan – Session 5 & 6 - Problems associated with implementation of small-scale biogas digesters in Sub-Saharan Africa	
Session 5	Practical problems
9.00	Introduction (Kenneth Yongabi, Phytobiotechnology Research Foundation, Cameroon)
9.15	Efficient functioning of biogas digesters under different environmental conditions (discussion session)
10.00	Availability of materials for construction of digesters – lessons and experiences in implementation in Cameroon and Nigeria (Kenneth Yongabi, PRF, Cameroon)
10.45	Break & coffee/tea
11.00	Integration of household biogas: co-digestion of feedstocks for maximum energy return (Greg Austin, Agama Biogas, South Africa))
11.45	Practical experiences of using biogas fuel and digested organic waste - (JB Magombe - farmer working with Heifer International, Uganda)
12.30	General discussion - What are the key practical risks & benefits associated with small-scale biogas digesters? - What research is needed to help reduce risks and maximize benefits? - How can we ensure that this research will improve access and uptake? - What environmental research is needed in the phase 2 DFID proposal and linked bids? OUTPUT – LIST OF ACTIVITIES LINKED TO PRACTICAL PROBLEMS TO INCLUDE IN (1) PHASE 2 DFID PROPOSAL & (2) LINKED BIDS
13.00	Break & lunch
Session 6	Measures needed to encourage uptake of biogas digesters
14.00	Introduction (Emma Casson, Uganda Carbon Bureau, Uganda)
14.15	The Multi stakeholder Approach in Biogas Technology Dissemination: The African Biogas Partnership Programme (Patience Turyareeba, SNV, Uganda)
15.00	Experiences from the Janeemo project (Grant Davidson, Macaulay Land Use Research Institute, Scotland)
15.45	Break & coffee/tea
16.00	Rural development opportunities associated with small scale biogas digesters (William Ssendagire, Heifer International, Uganda)
16.45	Using carbon markets (Bill Farmer & Georg Zenk, Uganda Carbon Bureau, Uganda)
17.30	Meeting initial investment costs for digesters – the need for (micro-) financing (Sylvia Nakami, Heifer International, Uganda)
18.15	General discussion - What are the key extension risks & benefits associated with small-scale biogas digesters? - What research is needed to help reduce risks and maximize benefits? - How can we ensure that this research will improve access and uptake? - What environmental research is needed in the phase 2 DFID proposal and linked bids? OUTPUT – LIST OF ACTIVITIES LINKED TO IMPLEMENTATION MEASURED TO INCLUDE IN (1) PHASE 2 DFID PROPOSAL & (2) LINKED BIDS
19.00	**Visit to Uganda Carbon Bureau and dinner at Lake Victoria Serena**

28th Jan – Session 7 - What longer term funding or research is needed to improve uptake of small-scale biogas digesters in Sub-Saharan Africa?	
9.00	General discussion on research needed
10.00	Break-out groups to prioritise research needed to address key issues Group 1: Environmental issues Group 2: Socio-economic issues Group 3: Engineering issues Group 4: Microbial issues Group 5: Issues in practical implementation
10.45	Break & coffee/tea
11.00	Plenary session to report on discussions (15 minutes each) Group 1: Environmental issues Group 2: Socio-economic issues Group 3: Engineering issues Group 4: Microbial issues Group 5: Issues in practical implementation
12.15	General discussion on phase 2 DFID research proposal and other potential sources of funding
13.00	Break & lunch
14.00	Break-out sessions to draft sections of phase 2 DFID proposal and initiate ideas for other sources of funding
15.45	Break & coffee/tea
16.00	Break-out sessions to draft sections of phase 2 DFID proposal and initiate ideas for other sources of funding continued
17.00	Plenary session - Presentation of drafts
18.00	Close

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Appendix B - Interdisciplinary Expert Workshop - Addis Ababa University, Ethiopia, 16-18 May, 2011

Jo Smith, Assefa Abegaz, Lisa Avery, Bedru Balana, Grant Davidson, Sue Edwards, Getachew Eshete, Kibreab Hailemichael, Stuart Leckie, Biruk Lemna, Yirgalem Mahteme, Rethabile Melamu, Jecinta Mwirigi, Linus Naik, Bob Orskov, Ambar Pertiwiningrum, Madhu Subedi, Vianney Tumwesige, Dereje Yilma, Kenneth Yongabi, Gebreegziabher Zenebe, Johnny Mugisha, Klaus Glenk, Peter Walekhwa, Emma Casson, Greg Austin, Karsten Bechtel, Robin Matthews, Peter Goude, Sean Semple, Norval Strachan.

Introduction

An interdisciplinary workshop was held at Addis Ababa University, Addis Ababa, Ethiopia from 16-18 May, 2011 to discuss the potential of small-scale biogas digesters to reduce poverty and improve the environment in Sub-Saharan Africa. The specific aim of the workshop was to consolidate the work of the last few months into review article(s) for publication in the peer reviewed literature. The agenda for the workshop is given in below. Invitees were limited to key experts in different disciplines associated with implementation of biogas digesters. Only participants who were expected to have a real contribution to any further research work were invited; this was to maximize the potential for interactions and discussions as well as to minimize costs of the workshop. The 21 participants included experts from 12 organisations from 6 different countries. The full list of participants is given below.

The workshop was organized into 4 sessions. Session 1 provided a review of the latest scientific literature into the position of biogas digesters in Sub-Saharan Africa. The socio-economic, educational, engineering, environmental and health related issues associated with using biogas digesters in Sub-Saharan Africa were summarized. Session 2 provided a review of the current position of biogas digesters in Ethiopia. In session 3, the participants moved to the field, the objectives being to better understand the potential of biogas digesters in Ethiopia, to stimulate discussion on the strengths and weaknesses of different digester designs, the different options for using digester slurry, the risks and benefits of installing a biogas digester, and the research needs for improving uptake of biogas digesters. In session 4 the discussions focussed on the publications to be consolidated over the next few months, identifying lead authors and participants for the papers.

The first workshop included participants from 5 countries: Uganda, South Africa, Kenya, Cameroon and Scotland. No participants were included from Ethiopia and so workshop 2 was held in Ethiopia to address this omission from our network. The outputs from this workshop will be an improved network of researchers; a possible further proposal to the EU under the expected call to African ACP and Mediterranean Partner Countries (KBBE.2012.3.4-01) on conversion of bio-waste in developing countries (worth up to 3,000,000 Euros); and a number of review papers to be submitted as a special Issue of an appropriate journal. The workshop was kindly opened by Biruk Lemma, Research Director of Addis Ababa University.

Agenda

16th May – Session 1 – Review of the Current Position of Biogas Digesters in Sub-Saharan Africa	
9.00	Registration & Coffee
9.10	Welcome (Assefa Abegaz, University of Addis Ababa, Ethiopia)
9.20	Opening remarks (Biruk Lemma, Research Director of Addis Ababa University)
9.30	Introduction and review of the issues covered in the first workshop held in Makerere University, Uganda (Jo Smith, University of Aberdeen, Scotland)
10.00	Review of most recent literature on socio-economic (Jecinta Mwirigi, Egerton University; Johnny Mugisha, Makerere University; Bedru Balana, James Hutton Institute; Klaus Glenk, Scottish Agricultural College; Peter Walekwha, Makerere University)
10:25	Review of most recent literature on educational issues (Vianney Tumwesige, Makerere University; Grant Davidson, James Hutton Institute; Emma Casson, Uganda Carbon Bureau)
10.50	Break & coffee/tea
11.00	Review of most recent literature on engineering issues (Linus Naik, University of Capetown; Rethabile Melamu, University of Capetown; Greg Austin, Agama Biogas; Karsten Bechtel, Makerere University)
11.45	Review of most recent literature on reduced carbon emissions due to deforestation (Madhu Subedi, James Hutton Institute; Robin Matthews, James Hutton Institute; Jo Smith, University of Aberdeen)
12.05	Improving carbon sequestration and nutrient use through integrated agroforestry (Bob Orskov, James Hutton Institute)
12.30	Review of most recent literature on health related issues; pathogen losses and indoor air quality (Lisa Avery, James Hutton Institute; Kenneth Yongabi, Phytobiotechnology Research Foundation; Norval Strachan, University of Aberdeen; Sean Semple, University of Aberdeen)
13.15	Break & lunch

16th May – Session 2 – Review of the Current Position of Biogas Digesters Ethiopia	
14.00	Biogas in Indonesia to support energy self-sufficient villages – lessons to be learnt for Ethiopia and Sub-Saharan Africa. Ambar Pertiwiningrum (Universitas Gadjah Mada)
14.45	Biogas for poverty reduction and climate change mitigation: The case of Ethiopia. Zenebe Gebreegziabher (Ethiopian Development Research Institute, Addis Ababa)
15.30	The Current Position of Biogas Digesters in Sub-Saharan Africa. Dereje Yilma (Ministry of Water and Energy, Alternative Energy Technology promotion & Dissemination Directorate office)
16.15	Break & coffee/tea
16.30	Composting and slurry as fertilizer from biogas. Sue Edwards (Institute of Sustainable Development)
17.15	Sector development in large scale dissemination of domestic biogas. Getachew Eshete (SNV)
18.00	Discussion on the Ethiopian Biogas Programme
18.30	Close

17th May – Session 3 - Visit to biogas digesters in vicinity of Addis Ababa	
Purpose of visits – to stimulate discussion on e. the strengths and weaknesses of different digester designs f. the different options for using digester slurry g. the risks and benefits of installing a biogas digester h. the research needs for improving uptake of biogas digesters Visit to 3 households: 2 rural (one male headed and another one female headed household) and 1 urban (showing a different application of the biogas digester output).	
9.00	Depart
	Lunch at Debrezeit
18.00	Return

18th May – Session 4 – Consolidation of presented material into a review article for publication in a peer reviewed journal	
9.00	Discussion on target journal
10.00	Discussion on paper content / message
11.00	Break & coffee/tea
11.15	Discussion on introduction and conclusions
12.15	Discussion on paper sections and assignment on workgroups
13.00	Break & lunch
14.00	Breakout into workgroups to draft paper sections 1. Essential literature 2. Section structure (sub-sections) 3. Sub-section content 4. Assign supporting literature to each sub-section 5. Agree tasks and timetable for delivery
16.00	Break & coffee/tea
16.15	Plenary to discuss progress
17.00	Resume breakout sessions to conclude 1. Confirm who will do agreed tasks 2. Confirm timetable for delivery
18.00	**Workshop Close**

Participants

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