DFID Interdisciplinary Expert Workshop on the Potential of Small-Scale Biogas Digesters in Sub-Saharan Africa - Addis Ababa University, Ethiopia, 16-18 May, 2011

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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 appendix A. 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 in appendix B.

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 provide 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.

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?

Small scale biogas digesters are an emerging technology because the technology exists, excellent ongoing programmes exist in a number of Sub-Saharan African countries, they have already been implemented in many other countries of the world, and translational research is now needed to support longer term, safe and sustainable implementation in Sub-Saharan Africa. This workshop follows on from a previous workshop, held in Kampala in January, 2011. At that workshop we considered the best way to build on the emerging technology of biogas digesters: what is the best design to use; what are the barriers to adoption; and how can uptake be encouraged? Three main types of digester are available for use in Sub-Saharan Africa: floating drum, fixed dome and flexible balloon digesters. Biogas technology has largely converged around fixed dome digesters, with ~40 million already installed in China and future plans to install ~6 million / year; a new programme initiated in India to upgrade the existing floating drum digesters to fixed dome design; and the African

Biogas Partnership Programme having backed the fixed dome design. This is because the fixed dome design is robust, can be prefabricated (which has advantages for obtaining credit, as the prefabricated unit represents a resource that can be claimed back by the creditors on the borrower defaulting on payments); and they can be made from local materials (which stimulates local businesses and trade). However, highly successful programmes exist in Indonesia and Vietnam based around flexible balloon digesters. These are favoured because they are cheap ($30-$100) compared to fixed dome and floating drum digesters ($700 - $1200). The optimum design of biogas digester depends on the contribution of different factors in the chosen setting, including technical, financial, user, institutional and environmental factors. Technical factors include water tightness, gas production, gas pressure, efficiency, water requirements, temperature sensitivity, scum release, sedimentation, super structure wear and tear, and co-digestion ability. The different designs of digesters can be given a qualitative score depending on the efficacy of the design with respect to these technical factors. On technical considerations, the fixed dome digester comes out as the most effective design. Financial factors include capital cost, operational cost and cost of alternative fuel. On the basis of these financial considerations, the flexible balloon design scores highest. However, if credit availability is also considered, the different designs are more equal as it is easier to obtain credit for floating drum and prefabricated fixed dome designs. Therefore, the optimum choice of design, based on financial considerations, depends on whether the farmer is willing to use credit facilities. User factors include time to initiation of gas production, space limitations, and convenience. On these factors, the flexible balloon design scores highest. Institutional factors include ability to implement quickly and quality assurance. On institutional factors, the floating drum design scores highest. Environmental factors include sanitation, household air quality, reduced deforestation, nutrient supply to crops, carbon sequestration in soil, and use of digester slurry as fish food. Scores for the different designs of biogas digesters on environmental factors are largely unknown. More research is needed in these areas.

The process of biogas production includes the stages of hydrolysis, acidogenesis, acetogenesis and methanogenesis. Yongabi et al (2009) showed how counts of mesophilic bacteria, coliforms, E.coli, yeast, salmonella and shigella, while being too numerous to count in the raw slurry, are much reduced in the digested slurry. Work needed in this area includes the determination of reduction in pathogens with different rates of throughput, different types of digester, and different types of organic wastes. Risks of handling also need to be considered. Sufficient data is needed to allow models to be developed that will predict the reduction in pathogens in any selected specification of biogas digester.

Globally, three billion people are exposed to biomass smoke in homes. Poor household air quality is linked to pneumonia, lung cancer and chronic lung disease. It is estimated that it leads to ~1.2 million premature deaths annually. It is linked to poverty, with poor people more likely than richer people to use fuels that result in poor household air quality (animal dung, crops; wood; and charcoal). The substances responsible for poor household air quality are fine particulate matter - ‘smoke’ ($PM_{2.5}$, PM_{10}, inhalable dust, respirable dust); carbon monoxide (CO); airborne endotoxins (inflammatory agents); and other toxic chemicals (PAHs, Arsenic, Aldeyhdes, Nitric Oxides, Benzene. Sulphur Dioxide). Work is needed to quantify the actual improvement in household air quality achievable through replacement of all or a portion of the current fuel use with biogas. Work is also needed to understand the potential negative effects of reduced fumigation of insects in the home if biomass fuel is replaced by biogas. There is great potential for developing powerful educational packages to promote use of biogas through the possible changes in household air quality.

Switching to biogas is often assumed to automatically result in reduced deforestation. However, fuel wood collection does not always result in deforestation: much firewood is obtained from land already being cleared for agriculture; dead and fallen wood may be collected rather than wood being obtained by felling of live trees (this practice can actually stimulate forestry growth); supplies may be obtained from trees outside forests (such as in agroforestry); or other fuel supplies may be used (such as dung or crop residues). The problems of fuelwood supply are often related to access rather than to supply. Work is needed to review the factors driving deforestation and its link to biogas. Further consideration of the role of REDD in promoting biogas digesters should also be considered.

The value of the digested slurry as an organic fertiliser (as compared to cost of nutrient value in fertiliser) may be ~5 times the value of the energy (as compared to cost of natural gas) produced by the biogas digester. Use of the digested slurry as an organic fertiliser relates not only to the supply of nutrients, but also to the supply of carbon to the soil, which improves water holding capacity and crumb structure, and so can increase yields much more than the inorganic nutrients alone. Carbon sequestration in the soil is dependent on the amount and decomposability of organic matter added to the soil. The effect of aerobic and anaerobic decomposition of plant residues and organic wastes is to decrease the decomposability and reduce the total amount of carbon added to the soil from a particular residue. Despite the reduced input of carbon, the effect of decomposition is usually to stabilise the organic matter sufficiently that more carbon will be sequestered from the addition of the decomposed organic material than the fresh organic waste. However, the impact of the decomposition processes on decomposability and quantity of carbon in the added organic matter has not been rigorously quantified. More scientific research into this is urgently needed.

Similarly, the use of organic waste to feed aquatic plants that then support a harvest of fish needs further research. Work is also needed to identify how fish ponds can be integrated into the farming systems that are used in Sub-Saharan Africa.

The outputs from the first workshop were a report, 3 research bids and the establishment of an interdisciplinary network of researchers working on biogas. Socio-economic barriers to adoption include social acceptance, economic potential and suitability of existing designs. An output from the first workshop was 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. The workshop also considered the risks associated with biogas digesters. These are contraction of diseases by increased handling of organic wastes; possible incomplete sterilisation of pathogens, resulting in pollution of water courses due to application of higher quantities of undigested material to crops; the potential for leaks or intentional venting of methane from biogas digesters (to avoid build up of pressure) actually increasing net emissions of methane and so contribute to additional climate change; the possible removal of carbon from the soil/crop system where in some designs of digesters, sludge sinks to the bottom of the digestion tank and is only cleaned out every 10 years; and the potential for economic hardship if householders obtain credit and then default on the payments. To address these issues, another output from the workshop was the submission of 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. Further research is also needed on flexible balloon digesters, which have great potential to provide a cheaper alternative to fixed dome digesters, but have been under-research in African conditions. A bid will be submitted to phase 2 of DFID NET-RC on the potential of small-scale biogas digesters to improve livelihoods and long term sustainability of ecosystem services in Sub-Saharan Africa (Jo Smith, University of Aberdeen, ~£200,000).

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 possibly to be submitted as a special Issue in Renewable and Sustainable Energy Reviews or the International Journal of Agricultural Sustainability. The workshop was kindly opened by Biruk Lemma, Research Director of Addis Ababa University. Details of the workshop sessions are give below.

Session 1 – Review of the Current Position of Biogas Digesters in Sub-Saharan Africa

Socio-economic issues (Jecinta Mwirigi, Johnny Mugisha, Bedru Balana, Klaus Glenk, Peter Walekwha)

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 (BORDA, 1990; Ni , 1995). This could be due to shortage of raw materials to feed the digester. African countries 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; quoted in Drovers, 2011). Note that to be directly comparable, these numbers should be reanalysed in terms of number of cattle per head of population. Another possible barrier to uptake is unavailability of land and water (Quardir et al, 1995). 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. 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 another 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, 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). 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 (ISAT, n.d.). The size of farm has a further 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. The availability of cheap and reliable appliances, and strong technical support, further increase uptake and long term use of the digester (Kuteesakwe, 2001). Finally, an 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).

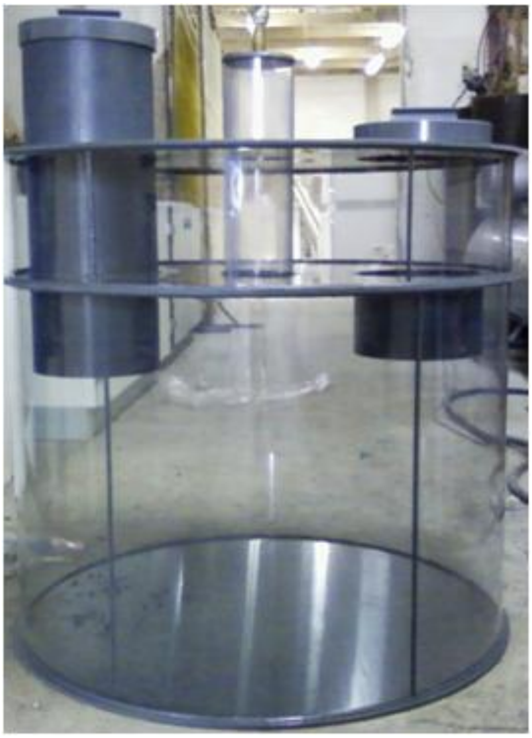
Why is uptake higher in countries such as Vietnam, where the national programme has been highly successful? 80% of the population live in rural areas. The materials used in construction are either cheap (polythene used in flexible balloon digesters) (Zhu, 2006), or are highly subsidised (Rogers et al, 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.

Knowledge transfer issues (Vianney Tumwesige, Grant Davidson, Emma Casson,)

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. 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.

Engineering issues (Linus Naik, Rethabile Melamu, Greg Austin, Karsten Bechtel)

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. 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. 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 includes 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 is 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.

A toolkit for use by the person providing support for the biogas digester is currently being developed at UCT. 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 included 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 startup problems, as well as items to solve structural problems, such as spare valves.

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.

Carbon emissions due to deforestation (Madhu Subedi, Robin Matthews, Jo Smith, Bob Orskov)

Woodfuel production (selling of woodfuel as a product in the market) has increased 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 (note, the significance of this should be quantified using a *t*-test). There is a relationship between income level and use of woodfuel and charcoal (Barnes et al., 2002), although 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). 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 favourable effect on reducing deforestation. However, this analysis does not consider that wood may be 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 is calculated from the ratio of the rate of carbon sequestration in trees and the rate of demand for woodfuel:

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

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 collection of 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.

Health related issues (Lisa Avery, Kenneth Yongabi, Sean Semple, Norval Strachan)

Health related issues associated with biogas digesters include both clear benefits and potential risks. The main factors are associated with indoor air quality and pathogen distribution in the environment.

Health problems linked to exposure to smoke from burning biomass include pneumonia, chronic obstructive pulmonary disease, cataracts, lung cancer, asthma, tuberculosis and low birth weight. Annually, 1.2 million premature deaths are related to poor indoor air quality, contributing to 2.5% of the total healthy life years lost. Most of the health effects are strongly affected by levels of fine particulate matter (PM2.5, PM10, respirable dust fraction). Carbon monoxide can be produced, which can cause acute poisoning. For other gases and biological components produced by burning biomass fuels (polycyclic aromatic hydrocarbons, endotoxin), the relationship to health is unclear and they are expensive to measure. By comparison with studies on LPG, switching from woodfuel or charcoal to biogas is likely to result in a cleaner, more efficient combustion, resulting in a ten-fold reduction in the levels of particulate matter. 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.

Health problems associated with spread of human and animal 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.

Session 2 – Review of the Current Position of Biogas Digesters in Ethiopia

Biogas in Indonesia to support energy self-sufficient villages – lessons to be learnt for Ethiopia and Sub-Saharan Africa (Ambar Pertiwiningrum and Rachmawan Budiarto - Universitas Gadjah Mada, Indonesia)

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). 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 supplier of spare parts. Recommendations based on experiences in Indonesia are to standardise the digesters used, and to encourage for 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 status of Biogas technology in Ethiopia (Dereje Yilma - Ministry of Water and Energy, Alternative Energy Technology promotion & Dissemination Directorate office)

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

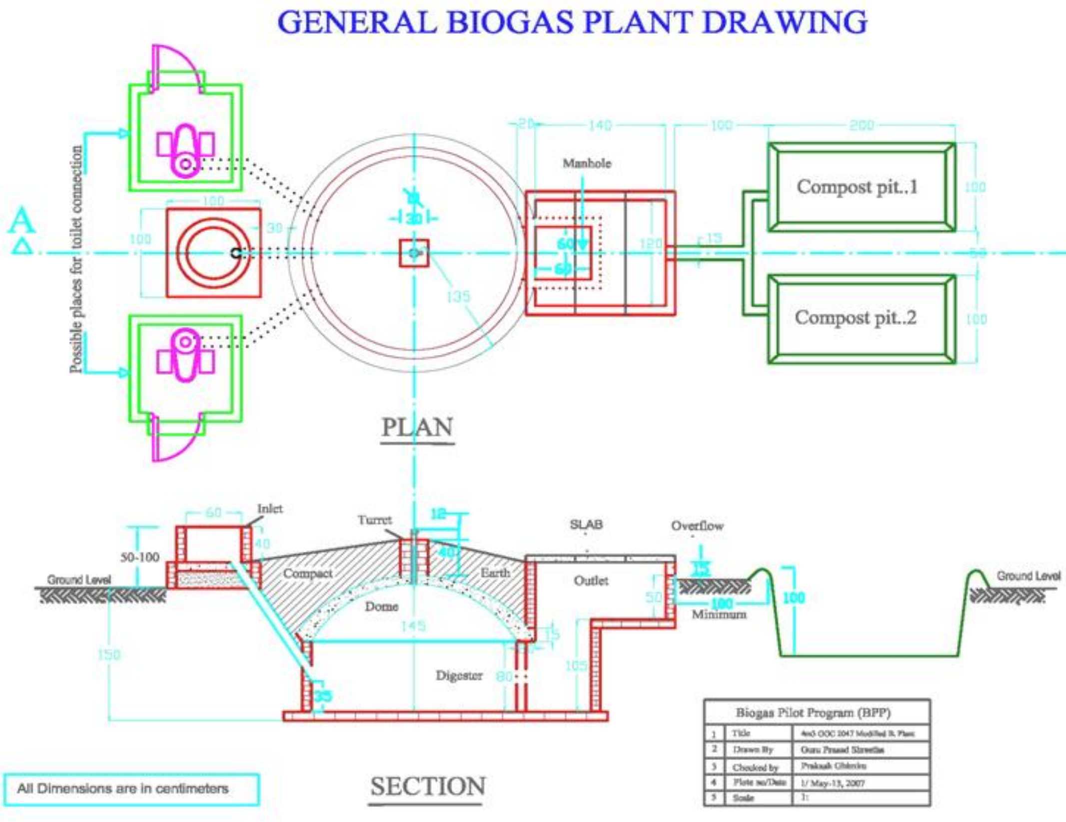
(1) the Alternative Energy Technical Dissemination and Promotion Directorate (AETDPD) covering the household energy efficiency programme through improved biomass fuel efficient stoves (Mirt, Gonzye, Lakech), the Rural Electrification (alternate energy) Fund (micro, hydro., diesel generators, solar and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

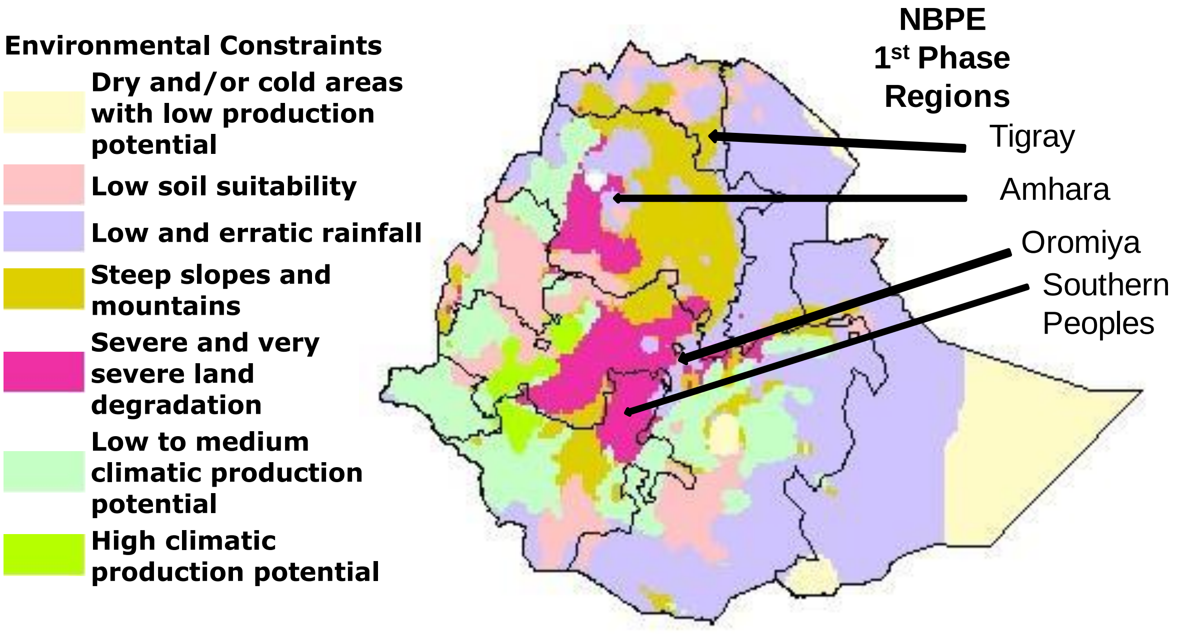


The total program investment is €16.6 million: contributions (for each installation) are 4% from the federal government, 3% from regional governments, 43% from each biogas user, 39% from donors (The Netherlands Government through HIVOS), and 11% and technical assistance from SNV Ethiopia. The Federal 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.

Biogas for poverty reduction and climate change mitigation: The case of Ethiopia (Zenebe Gebreegziabher - Ethiopian Development Research Institute, Addis Ababa; Arie Oskam - Wageningen University)

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. The Program plans to construct 14,000 plants in the period 2010 to 2013, in the Amhara, SNNPRS, Oromiya, and Tigrai 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.



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 (**ref**) of 0.064 – 0.097 and a change in poverty severity index (**ref**) 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.

Composting and slurry as fertilizer from biogas (Sue Edwards - Institute of Sustainable Development, Addis Ababa)

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.

Sector development in large scale dissemination of domestic biogas (Getachew Eshete, SNV)

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.

Session 3 - Visit to biogas digesters in vicinity of Debre Zeit

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. 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 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, 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.

Larvae of the rose chafer bugs 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. 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.

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
AT: 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.

Session 4 - Consolidation of presented material into review articles for publication in a peer reviewed journal

It was decided to publish a number of papers from the reviews initiated here, collected together as a high impact special issue. The target journal could be one of the following:

Renewable and Sustainable Energy Reviews (Impact factor 4.842);
Energy of the environment;
International Journal of Agricultural Sustainability;
Sustainable Development;
International Journal of Sustainable Development;
Biomass and Bioenergy;
Journal of Agricultural Systems.

Jo Smith will investigate and contact editors as soon as possible.

The proposed titles and lead authors for the proposed publications are given below. Although there are too many titles for a single special issue here, it is envisaged that these titles will be refined and some papers amalgamated over the coming months. Lead authors should contact co-authors for input; co-authors should also contact lead authors to make them aware of their interest.

Environment (English editor = Jo)

1. Biogas, soil fertility management and carbon sequestration (Jo)
2. Possible impact of biogas installations on deforestation (Madhu)
3. Holistic farming systems and biogas (Bob)

4. Challenges and prospects of biogas installations in urban households compared to rural households (Linus)

Health (English editor = Lisa)

5. Impacts of biogas on household air quality (Sean)
6. Review of challenges associated with pathogen reduction in anaerobic digestion, biogas generation in SSA (Lisa)
7. Review of occupational diseases due to agriculture (Kenneth)
8. Processes of microbial anaerobic decomposition (Ambar)

Socioeconomics (English editor = Klaus)

9. Socioeconomic constraints to biogas adoption in SSA (Jecinta)
10. Cost / benefit analysis, cost effective analysis & risk analysis of biogas technology in SSA (Klaus)
11. The impact of biogas for reducing poverty (Bedru)
12. The carbon market and biogas (Stuart)

Engineering (English editor = Jo)

13. Factors that govern stability of small scale systems and the need for effective monitoring (Linus)
14. Issues with the structural design of appliances associated with biogas digesters (cooking equipment, stoves, lighting etc) (Vianney?)
15. Comprehensive review of reactor designs including impact on biological processes (Greg)

Knowledge transfer (English editor = Grant)

16. Using innovation system framework to understand low dissemination of biogas in developing countries (Thabi)
17. Knowledge dissemination issues associated with biogas (Grant)

Deadlines – The structure of the paper should be circulated around the whole group by the lead author, providing suggestions for who should make contributions (June 18th). If any members of the group would like to contribute to a particular paper but have been omitted, they should suggest their contribution to the appropriate lead author.
Draft contributions should be sent back to the lead author by October 1st.
Papers should be submitted to Jo Smith by December 15th.
An internal edit of papers will be completed and returned to the authors by March 1st.
The special issue will be ready for submission to the journal editors by May 1st.

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Appendix A – Agenda for the workshop

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 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 Visit to 4 households: 2 rural (one male headed and another one female headed household) and 2 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**

Appendix B – Workshop participants

First Name Surname	Organisation	Email address	Postal address	Telephone
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