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FINAL REPORT

BIOSYRCA PROJECT

DESIGNING SHORT-ROTATION COPPICE BASED **BIO**ENERGY **SY**STEMS FOR **R**URAL **C**OMMUNITIES IN EAST **A**FRICA

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Designing short-rotation coppice based BIOenergy SYstems for Rural Communities in east Africa
BIOSYRCA project

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1 EXECUTIVE SUMMARY

Access to modern energy services, such as electricity, is crucial in order to achieve development goals of poverty reduction, improved education, and environmental sustainability. Sub-Saharan Africa is dramatically behind other regions of the world in rural electrification. For example, in Uganda, about 84% of households are located in rural areas, but less than 1% of them have access to modern energy services. People without access to modern energy services rely on increasingly scarce traditional biomass sources and inefficient, polluting conversion systems, such as traditional cookstoves.

East Africa has one of the greatest potentials for energy biomass production in the world, but the use of modern bioenergy systems has largely been neglected. However, given increased energy demand, rising fossil fuel prices, and power shortages, there is now increasing regional interest in assessing the potential for distributed bioenergy systems from both the national authorities and private business like agroindustry. Several bioenergy systems are in various stages of assessment, installation and operation.

The objective of the BIOenergy SYstems for Rural Communities in east Africa (BIOSYRCA) project was to conduct a feasibility study assessing the potential for a bioenergy system at the Kyangwali settlement in Hoima District, Uganda as a pilot project to investigate the suitability of bioenergy systems for rural electrification. The bioenergy system would use biomass from fuelwood plantations to generate electricity. The feasibility study assessed feedstock supply, biomass conversion technology, socio-economic factors of the settlement, and overall sustainability of such a system.

Species native and exotic to the ecoregion of Kyangwali were investigated with regards to their fuelwood potential. The factors influencing the species choice were coppicing ability, biomass yield, drought resistance, pest resistance, and impact on soil fertility.

Project activities included an investigation of a biomass gasification technology applied at the Muzizi Tea Estate owned by James Finlay Uganda, the biggest national tea producer, close to Fort Portal. By means of an extensive dataset on the economic performance, efficiency, and environmental impact of this pilot plant, we performed an economic analysis of competitive energy production including capital, labor, and operational costs in comparison to existing electricity systems based on diesel generators. An emphasis was given to the analysis of the fuelwood supply coming from internally owned and managed Eucalyptus plantations.

Feasibility study activities at the Kyangwali settlement included identification of local stakeholders and decision makers, stakeholder meetings to integrate their views on sustainability, an electricity demand assessment, purchasing power assessment, and a bioenergy impact assessment for the community. The community's human and social capacity was assessed in a participatory approach in order to determine its current and future requirements with respect to locally generated bioenergy.

Results indicated that no single species ranked highest for use as fuelwood input for a bioenergy system in Uganda. Suitability of species depends on many factors specific to a site such as biophysical limits or available knowledge on and acceptance for a species. Information on the production rates of different species in the region is very limited, especially for short rotation coppice systems. Of the information available the most reliable is for *Acacia mearnsii, Eucalyptus grandis, Sesbania sesban,* and *Markhamia lutea*. Besides ranking highest in certainty of information, these four species also received high rankings in their suitability for fuelwood applications. *Sesbania* is an attractive alternative due to its high biomass productivity, wide acceptance and nitrogen fixing abilities. In addition to being native to Uganda, *Markhamia* is a promising species for its pest and disease resistant nature, especially to termites. Despite

being of exotic origin in Uganda, *Acacia mearnsii* should be considered especially for drier sites and is increasingly also seen as an alternative to *Eucalyptus* for large industrial plantations especially in areas with increasingly frequent weather extremes.

To identify and unlock the potential for bioenergy through SRC plantations in Uganda, we recommend the establishment of mixed and single species trials with aforementioned species, in collaboration with local partners from research such as the Centre for Research on Energy and Energy Conservation (CREEC) and potentially interested communities, industrial users, or investors on various sites and locations in Uganda.

Information collected on the gasifier that has been installed at James Finlay Uganda indicated that this technology can be an economically viable and environmentally preferable alternative to diesel generators for power production. Although in January 2007 not running yet at the rated capacity of 200 kW (average production was 87 kW at a 50 % load factor), the system is already producing cheaper power than diesel generators can provide. Electrical efficiency is currently at 15% but could be boosted to the rated 24% with the implementation of minor improvements, including the creation of stable loads of >150 kW and better control mechanisms for the system.[1]

Economic and social activities in Kyangwali settlement center around the administration buildings and adjacent Kasonga Trading Center. Both, the administration buildings and many businesses in Kasonga have individual generators running on fossil fuels to serve their electricity needs. This electricity supply system is expensive to run and maintain and in many cases inefficient. At the same time, the Kasonga Trading Center and the various administrative institutions possess the social and human capacity to run a centrally located electricity supply system, as well as the economic purchasing power to buy electricity services.

The Kasonga Trading Center with the adjacent administration buildings are a typical location for a small-scale bioenergy pilot project that could be replicated many times in rural Uganda and beyond, if successful. A bioenergy system serving both the administrative buildings and Kasonga Trading Center could provide cheaper electricity services to more people than is currently the case. To develop this project and make it successful, the communities concerns about training, ownership and planning and monitoring, which were identified through a multi criteria assessment process with stakeholders, need to be addressed. In addition, further assessment and design efforts would be needed to make a project successful. For instance, although running on a potentially inexpensive fuel (woody biomass at 0.03 US$/kWh at Muzizi Tea Estate vs. fossil fuel costs of 0.3 US$/kWh), gasification systems are characterized by high capital costs (2,087 US$/kW at Muzizi Tea Estate). Therefore, some of the issues that require more research and interaction with a community to make a pilot system work are i) favorable project financing schemes to reduce the barrier of high capital costs for the pilot, ii) viable business models developed with the community that can be run by the community, and iii) plantation establishment and management plans that include clear user rights for the established plantations or alternatively the development of an effective community based forestry scheme that would support farmers in woodlot establishment and maintenance.

The successful demonstration of sustainable bioenergy systems in this part of Uganda based on woody biomass from SRC and/or plantations in this region would provide a base for expanding this model to other regions where a sustainable and reliable power supply is essential for human development. However, in order for a model project to be successful it is important to identify all barriers and design effective solutions. The results of this project indicate

[1] With changing the ignition timing, an average output of > 150 kW became reality when finalizing the report in July 2007

that the main barriers appear to be high capital costs of gasification systems, the need for human capacity building, absence of viable business models, creation of stable loads for bioenergy systems, designing and implementing sustainable fuelwood supply chains, and a lack of information on promising fuelwood species. Suggestions are presented in this report to address these barriers so that a demonstration bioenergy project would be successful.

2 INTRODUCTION

Uganda currently faces a major energy shortage. Currently, only 5% of the population in Uganda has access to electricity and in rural areas it is as low as 1% (MWLE 2001). In a country of over 25 million inhabitants, only 200,000 residential and commercial customers are connected to the grid. The situation in other countries of Sub-Saharan Africa is comparable. Without access to electricity, it will be difficult to reach the Millennium Development Goals of poverty reduction, improved education, and environmental sustainability (Modi et al. 2006).

People without access to modern energy services rely on increasingly scarce traditional biomass sources and inefficient, polluting conversion systems, such as traditional cookstoves. Women and children inhale deadly indoor fumes while cooking (Bailis et al. 2005) and spend considerable amounts of their productive time collecting dwindling and distant supplies of wood. A lack of access to modern energy services results in a lower quality of life, limited opportunities for economic development, and environmental degradation. Surprisingly, the absence of basic modern energy services is not necessarily a result of financial poverty. Many poor already pay more per unit of energy than the better off due to inefficient technology and corruption (DFID 2002).

In Uganda total installed capacity is around 400 megawatts electrical (MWe) – mainly from hydropower installations along the Nile – but production recently has been significantly lower because of low water flows. Accounting only for those Ugandans who have grid connection already, currently daily electricity shortages are estimated to be in the range of 200-250 MWe.

Thermal power production with fossil fuel powered generators increased significantly during the last two years and is the only solution being actively pursued so far to address electricity shortages in the capital. Increased demand and rising fossil fuel prices have caused the grid electricity supply to deteriorate, and even in the capital power cuts are common now. Unreliable electricity services forces industries to purchase and operate generators as backup systems, accounting for an estimated 34% of their total investment (Eberhard et al. 05).

In 2007, more than 50% or 200 MWe of the power will be produced by emergency thermal generators with feed-in tariffs of US$ 0.27/kWh. This, linked with the ninth highest population growth rate in the world, creates a major development issue for the country. Considering climate change, unstable water levels, unreliable fossil fuel supply, high production costs, its contribution to air pollution, and dependency on imports, this is not a sustainable solution and indigenous power solutions must be found.

There is a need to broaden and diversify power production in Uganda and design systems that will provide power to local communities and agro-businesses such as tea plantations. Renewable energy seems to be the only sensible and sustainable option for a land locked country with high fuel import costs. Proven small-scale conversion technology, like biomass gasification, can be operated by local community members after limited training. It provides efficient and CO_2 neutral energy at the local level (Nouni 2007, Ravindranath et al 2004). Such power systems can supply power for enterprises that can add value to agricultural products such as grain mills, drying or cooling chambers, run machinery to manufacture products locally, improve local health services by refrigeration of vaccines and operation of medical equipment, enable access to communication and information technologies, and increase daily productive hours by providing light in houses and commercial and public buildings. Creating successful bioenergy systems using local structures would lower reliance on energy imports, increase community self-reliance, and improve the quality of life and environmental conditions at both a local and global level. This situation, together with Uganda's liberalized electricity market, creates an opportunity to provide electrical energy from biomass by utilizing available land and high yield potential found in Uganda.

East Africa has been identified as a region with one of the greatest potentials for biomass production for energy in the world (Hoogwijk et al. 2005). This is due in part to the region's large amounts of marginal land that are not useful for food crop production, but could produce sustainable yields with Short Rotation Coppice (SRC) systems on steep slopes, degraded land or agricultural fallows (Siriri & Raussen 2003). SRC systems integrate principles from both agriculture and forestry. Trees or shrubs with high biomass production are planted at high densities (1,000 - 20,000 plants per ha) and harvested at intervals ranging from one to several years. Species used in these systems resprout (coppice) after harvest, maintaining high productivity so that additional crops do not have to be replanted and a perennial crop is established across the landscape. SRC systems produce many environmental and rural development benefits like soil conservation, improvement of landscape and biological diversity, and carbon sequestration (Aronsson et al. 2000, Heller et al. 2003, Tolbert et al. 2002, Volk et al. 2004). By providing rapidly growing, local sources of wood, SRC reduces pressure on natural forests and reduces the amount of energy that must be imported.

3 RATIONALE OF BIOSYRCA

The objective of the BIOSYRCA project was to conduct a feasibility study to assess the potential for a bioenergy system at the Kyangwali settlement in Hoima District, Uganda; the bioenergy system would use biomass from SRC to generate electricity. The feasibility study assessed feedstock supply, biomass conversion technology, socio-economic factors of the settlement, and overall sustainability of such a system.

Bioenergy systems are complex because their three components – feedstock supply, conversion technology and energy allocation – are influenced by environmental, economic and social factors. Assessing these factors and their interdependency is essential to determining the potential success of a project and its contribution to sustainable development since the failure of one component can lead to collapse of the entire system. Therefore, the approach chosen for the BIOSYRCA project covered the following tasks of:

- Native species identification and preliminary productivity assessment (Feedstock Assessment). Native and exotic species were investigated with regards to their SRC potential. A set of criteria to determine their suitability in SRC systems was developed and selected species were ranked.
- Technology test and assessment. The focus of this task was to observe and collect data on a gasifier system that is running at Muzizi Tea Estate of the tea producer James Finlay Uganda and to use this information to assess the potential for applying the technology in a rural community. Conclusions were made for the application of this technology for electrification purposes of rural communities.
- Socio-economic assessment of Kyangwali settlement. The focus of this task was to visit a community in Uganda where conditions might be favorable for a gasification system and assess the socio-economic conditions of the community and potential impacts of such a

system. The community chosen for this portion of the project was Kyangwali settlement in Hoima District, Uganda.

- Overall sustainability assessment. The conclusions and insights from the previous tasks were merged into a sustainability assessment for a bioenergy system using a wood gasification at Kyangwali covering feedstock supply, conversion technology, and energy allocation issues considering economic, ecological, and social factors.

4 DATA COLLECTION

4.1 Study sites

The overall project focused on two sites in western Uganda, the Muzizi Tea Estate in Kibaale District, owned by the tea producer James Finlay Uganda Ltd. (JFU), where a wood gasifier is currently operating and the Kyangwali settlement in Hoima District. (Figure 1).

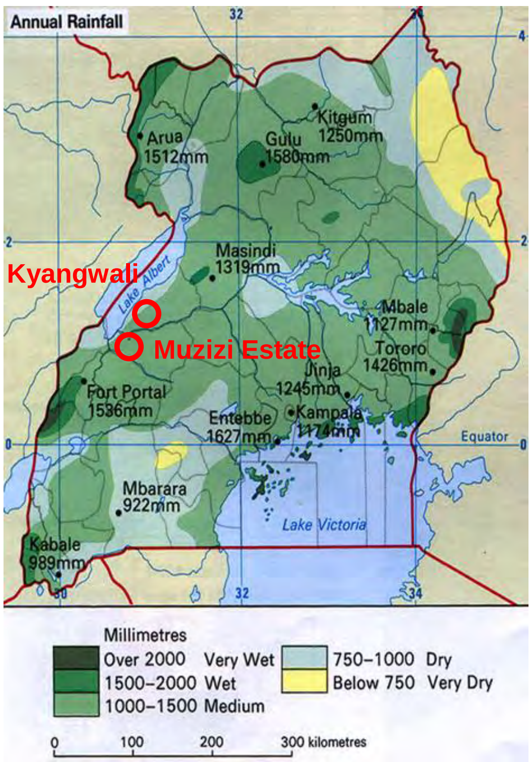

Figure 1: Rainfall map of Uganda.

Figure 2 : Topographic map of Uganda

Situated around 1,100 m above sea level (Figure 2), both sites have similar climatic conditions. Rainfall is distributed over two rainy seasons with one running from March to July and a shorter one from September to November. Although slightly drier than the Muzizi Estate, Kyangwali receives around 1,300 mm of rain per year. Droughts in dry seasons are a problem for establishing woody plants in the region.

Ecoregion

Both study sites are located within the same ecoregion 'Albertine Rift montane forests' (World Wildlife Fund 2007). Covering 103,900 square kilometers in Central Africa, it includes eastern portions of the Democratic Republic of the Congo, extending into Uganda, Rwanda, Burundi, and Tanzania (Figure 3). Assuming relatively low human impacts, the natural biomes are tropical and subtropical moist broadleaf forests.

The Albertine Rift Montane Forests are described as follows (World Wildlife Fund 2007):

"The severe geological history has resulted in a diversity of climatic regimes. While the Rift is located in the center of tropical Africa the high mountain regions extensively modify the climate, with a more temperate climate occurring in the highlands. Average rainfall throughout the mountain range varies between 1,200 to 2,200 mm per annum, although it is locally more in some mountain areas.

The ecoregion is dominated by montane rainforest […], but in the west, marginal fringes of the Guineo-Congolian rainforest impinge on the lower slopes (down from 500-800m), and forest/savanna mosaic habitats border it to the east in Uganda, Rwanda and Burundi. At altitudes above 3500 m, montane rainforest grades through Juniper forest and Ericaceous Heathland into the tussock grass and Giant Lobelia dominated altimontane vegetation of the Ruwenzori-Virunga Montane Moorland ecoregion."

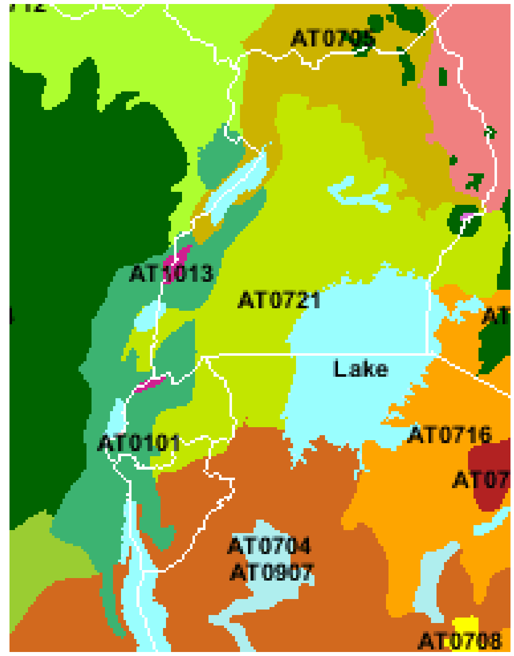

Figure 3: Ecoregion Albertine Rift montane forests AT0101 (World Wildlife Fund 2007).

4.2 SRC suitable species

For identification and assessment of suitable biomass species, activities included literature reviews, field reconnaissance surveys of plantations and field trials at Kyangwali settlement, the Muzizi Tea Estate of JFU, and trials at Nyabeya College, Masindi. Additionally, local community members and national and international experts were interviewed.

The following criteria were used to identify suitable SRC species for the target region:

- *Ability to coppice*: A species ability to resprout over several harvest cycles when cut
- *Biomass productivity (productivity potential):* Aboveground productivity of woody biomass measured in dry tons/ha/year with minimum additional input such as fertilizers, herbicides, irrigation;
- *Survival capacity*. A species' resilience against diseases and pests (e.g. termites), competition from weeds and its tolerance for limiting soil conditions (such as nutrient availability, water holding capacity, rooting depth, bulk density etc.) or droughts and other weather extremes;
- *Ecosystem integrity.* A species suitability to cope with a given environment. This is especially important when introducing exotic species, but is also true for native species because wide scale planting of a single species increases risks for a catastrophic failure from biotic or abiotic stress and reduces biodiversity across the landscape;

- *Propagation*. The ease of reproduce planting stock. For mass production, it is favorable if unrooted cuttings (parts of young branches or stems) can be used for planting stocks. Other considerations for propagation purposes are the availability and diversity of planting material (varieties) to support planting on large and diverse sites. Using four to six different varieties of a given species is recommended to minimize biotic and abiotic risks and maintain genetic diversity across the landscape;
- *Ease to establish and maintain a plantation*, including preparation of the planting site to reduce weed competition and to provide suitable soil conditions for planting and early growth. Species with rapid early growth rates will be more likely to out compete weeds and can be established with a minimum of early tending;
- *Growth shape*; for woody biomass for energy production, multistemmed growth is desirable since small diameters reduce the need for splitting of fuelwood after harvesting;
- *High quality fuelwood*; while the energy content of most hardwoods is similar, higher density wood reduces the volume of material required to supply a given amount of energy. Low moisture content of green wood allows improved efficiency of conversion technologies since less water is lost through evaporation;
- *Intercropping potential*; when intercropping SRC with other crops (e.g. food crops) in agroforestry systems, species with non spreading root systems are desirable to reduce competition with crops for nutrients and water. Rooting characteristics are also influenced by site conditions and the design and management of the agroforestry systems. Aboveground competition for light can be minimized by selecting species that have a more upright habit;
- *Local acceptance*; especially for small-scale projects that rely on woody biomass from the local community, traditional knowledge, use and acceptance of species is an important selection criteria. Compared to newly introduced species, there is already local knowledge on maintenance, propagation, or the multiple uses for a certain species and the development of new systems based on this knowledge increases adoption rates;
- *Nitrogen-fixing*; plant-available nitrogen in soils is often an important limiting factor for plant growth. When aiming at improving productivity of soils, increased availability of nitrogen can boost production and improve soil quality through fine root turnover and the return of leaf litter to the soil. Species that are able to fix atmospheric N through symbiotic associations with bacteria in the soil provide an additional benefit and reduce the need for N inputs from other sources;
- *Non timber products*; the ability of a species to produce non timber products such as palatable twigs and leaves for livestock fodder, fruit or honey production, medicinal uses, or human consumption can be important, especially in subsistence farming systems;

4.3 Wood gasification technology at Muzizi Tea Estate

Muzizi Tea Estate is owned by James Finlay Uganda (JFU), a subsidiary of John Swire & Sons Limited (the Swire group) based in the UK. JFU comprises five tea estates totaling over 3,000 ha in Uganda and is Uganda's largest single producer of black tea, growing and processing over 10,000 tons annually. JFU is responsible for over a quarter of Uganda's tea exports.

The Muzizi Tea Estate of JFU is located in Kibaale District in western Uganda (see Figure 1). It contains 371 ha of tea (*Camellia sinensis*) and 99 ha of Eucalyptus (*Eucalyptus grandis*) plantations. The Eucalyptus plantations were originally established to provide fuelwood for the tea drying process. The estate produced 1,200 tons of black tea in 2006 and employs around 400 tea pluckers and 70 factory workers in addition to the management staff. The tea is transported to Mombasa, Kenya, where it is auctioned. Mean prices achieved in 2006 were around US$ 1.5 per kg.

Energy demand for tea production consists of heat for tea drying and electricity to run processing lines, fans in withering troughs (pre-drying the tea), and other appliances. Being off the grid, Muzizi Estate depends on expensive diesel generators for electricity production. JFU replaced one of its diesel generators at its Muzizi Tea Estate with a wood gasification system as a pilot project to offset its diesel fuel costs. This project was designed to determine if it would be wise to make similar substitutions at its other tea estates. The system is based on wood gasification; wood is burnt in a controlled oxygen environment producing woodgas. The gas produced is cooled, cleaned and runs a gas engine to produce electricity (see Figure 4). Heat is collected from the system and used in the tea drying process. The gasifier is run on fuelwood from the Eucalyptus plantations on the estate.

The power conversion system is the GAS 250 system from Ankur Scientific, India. It is rated at 200 kW net electricity output and is installed in a shed measuring 10 m x 20 m, which does not include wood storage and water cooling pond (Figure 4). The pre-feasibility study, system design and choice of manufacturer for the gasifier system were carried out in 2005. The gasifier system was installed and commissioned in May 2006 and has been running consistently since August 2006. It is the first application of its kind using gasification technology in scales > 10 kW in East Africa.

SUNY-ESF visited the Muzizi Tea Estate was visited in January 2007 and conducted extensive interviews with engineers, management, employees, and plantation managers on the performance of the bioenergy system including wood demand and supply, energy efficiencies, labor and material input, waste stream management, financing, and overall performance. Comparable data was also collected on the diesel generator. In collaboration with the Centre for Energy and Energy Conservation (CREEC) at the Faculty of Technology of Makerere University, Kampala, a dataset from the gasifier covering 41 days from December 12th 2006 to January 23rd 2007 was used to analyze the electrical efficiency of the system .

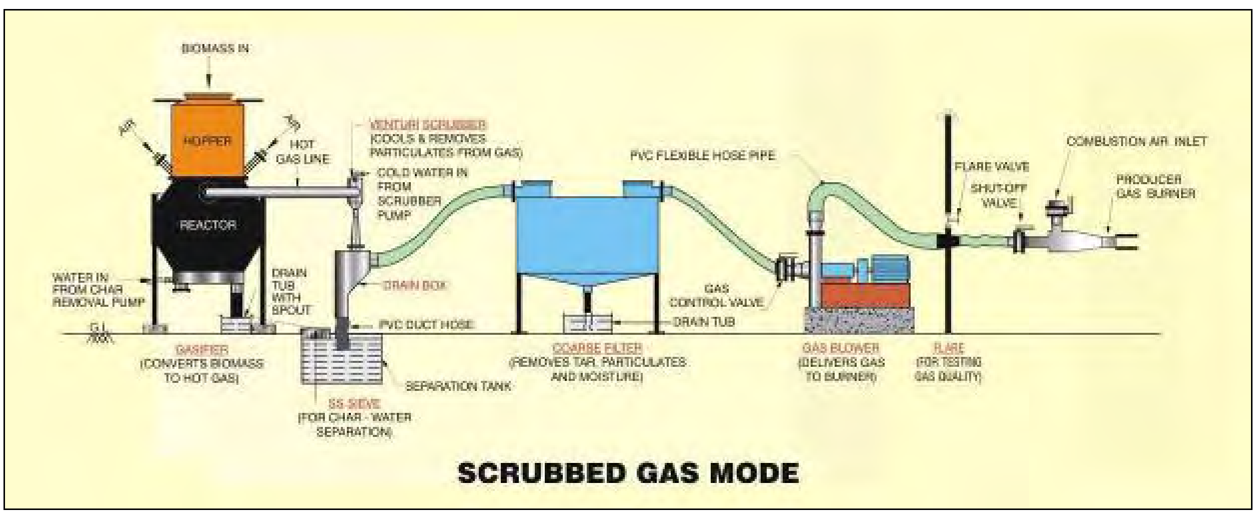

Figure 4: Simplified schematic gasification process (Ingvar 2007).

4.4 Kyangwali settlement

4.4.1 General introduction to Kyangwali

The Kyangwali Refugee Settlement is located in Hoima District, Western Uganda (Figure 2) and is home to international refugees. It covers 91.5 km^2 (9150 hectares) of government owned (gazetted) land and is situated next to Lake Albert bordering the Democratic Republic of Congo (DRC). The first refugees were Tutsis from Rwanda who arrived in 1967. Before this time, the gazetted land was a wildlife reserve with a tropical moist broadleaf forest, the typical natural biome for this ecoregion (World Wildlife Fund 2007). This original forest has been removed in most parts due to the high demand for agricultural land and fuelwood and is now predominantly agricultural land, settlement, unmanaged and degraded woodlands.

Currently, Kyangwali is a permanent home to about 19,000 displaced people. The population is fairly stable as it is officially closed. The refugees come primarily from Sudan (63%), and the Democratic Republic of Congo (33 %) and the remainder from Rwanda and Ethiopia. There are 4,000 to 5,000 family households in Kyangwali with four to five members per family. The population has been fairly stable during the last 6 years. Except for the trading centers where most of the non-agricultural economic and social activities take place, the refugees live in villages often together with fellow refugees from their home countries or locales in a well established social community. The settlement administration does not expect a dramatic change in the total population of Kyangwali in the near future.

Of 91.5 km^2 that are covered by Kyangwali, 25 km^2 are under agricultural cultivation. Major crops are corn, beans, rice, sorghum, groundnuts, soybeans, and tobacco. The residual is covered by homesteads, unmanaged rangeland with some cows and goats, protected wetlands, and heavily degraded woodlands. Kyangwali no longer relies on food imports and now exports 5,000 tons out of 8,000 tons of crops produced annually. Average household earning is 400 US$/yr generated nearly exclusively from agriculture.

The settlement is under direct control of the government of Uganda and administered by the United Nations High Commissioner for Refugees (UNHCR). Action Africa Help (AAH), an international non-governmental organization (NGO) based in Nairobi, has run Kyangwali with majority funding from UNHCR since 2000.

4.4.2 Kasonga trading center and administration buildings

Kasonga Trading Center (referred to as Kasonga) is located at the main entrance of Kyangwali next to the administration buildings of Kyangwali. Kasonga is the largest trading center in Kyangwali. To assess the feasibility of a bioenergy pilot project at Kyangwali, the area that encompasses both the administration buildings and Kasonga was selected as a prime location for a bioenergy pilot project mainly as it hosts all business types with high current and potential electricity loads concentrated in a very confined area keeping connection and grid-extension costs to a minimum.

Situated along a 200 m road (Figure 5), the core of Kasonga consists of 36 buildings including two combined cinema and cell phone charging businesses, three barber shops, two public phones, a combined metal workshop and cell phone charging business, a butcher, 12 convenience stores, a pharmacy, one clothing store, two tailors, four pubs/restaurants, 8 housing units, and 78 homes associated with the businesses.

Figure 5: Kasonga Trading Center at the main entrance of Kyangwali.

The Kyangwali settlement was visited twice in January and February 2007 for a total of 14 days to study the current electricity supply and use and to assess the potential of a bioenergy system. Information provided in this report was mainly gathered during this time. Activities included extensive field visits, informal meetings with local government officials, NGO representatives, elected representatives of the settlement, an energy survey of the main trading center Kasonga in Kyangwali and two workshops that were attended by key decision makers from the community. These workshops were scheduled at the end of the visit and followed extensive discussions and exchanges with leaders and businesses in the community to initiate the thought process and to allow reliable identification of key stakeholders by means of the snowball system[2]. Ten people were invited to both workshops. Nine people participated in each workshop. Participants represented the local and national government, NGOs and gender groups contributing a wide range of social, economic, and environmental expertise and insight.

The purpose of the workshops was i) to discuss and analyze the current electricity situation in Kyangwali and Kasonga, ii) to introduce the participants to the gasification technology and its financial, social, and environmental implications, and iii) to gather their opinions on the sustainability of the current electrical system versus a gasification based electrical system.

A Business As Usual (BAU) alternative was defined (individual generators and other energy services substitutable by electricity such as lighting) as well as a competing bioelectricity alternative. In a participatory setting, alternatives were depicted by graphic flow models visualizing influences of systems components on each other and describing causal loops not only of material and energy flows but also on social interactions. The workshop facilitator provided stakeholders with relevant information such as on wood consumption of bioelectricity systems, required land for fuelwood production, local purchase power, or local power demand for electricity and energy services which can be substituted by electricity such as lightening with candles.

Such participatory modelling for stakeholder facilitation resulted in identifying crucial criteria for a Multi-Criteria Analysis (MCA) evaluation process comparing alternatives. Eight key stakeholders took part in the MCA evaluation. An MCA tool, the Analytic Hierarchy Process (AHP) was deployed. The AHP is one of the most widely used MCA approaches and has a

[2] Snowball system: Assumed key stakeholders are asked to name other key stakeholders. In an iterative process those persons mentioned are asked again until no new names occur anymore (Reed et al. 2006).

proven track record to identify key criteria and performance of alternatives (Saaty 1997). More recently, the AHP has been widely applied to Natural Resource Management problems (e.g. Schmoldt et al. 2001). The AHP is a “ratio scale theory” based on a pairwise comparison of criteria and a subsequent ratio scale estimation for each criteria usually using a nine point scale. This approach allows the use of qualitative criteria as it does not need criteria values. This pairwise comparison has proven extremely intuitive and practical (Kangas and Kangas 2005). In a first step, a problem hierarchy is built encompassing a goal, criteria, and alternative hierarchy. In subsequent steps, criteria are compared pairwise to reveal their weights followed by a pairwise comparison of alternatives considering each criterion. The AHP offers several tools for sensitivity analysis to identify leverage points in decisions and test robustness of assessments.

5 RESULTS

5.1 SRC suitable species

Table 1 provides an overview of the biophysical limits of the species identified as potential SRC species in the BIOSYRCA project (primary source World Agroforestry Centre 2003). Information in this table is restricted to a few biophysical characteristics. Quantitative and reliable figures on current use, propagation, biomass productivity etc. of the species is very limited, varies widely or comes from uncertain sources.

Table 1: Biophysical limits of selected SRC species.

ORIGIN TO UGANDA	SPECIES	ALTITUDE RANGE	RAINFALL RANGE	TEMP. RANGE	SOIL
		m	mm/year	°Celsius	
Native to Uganda	*Markhamia lutea*	up to 2,000	900 – 1,200	12-27	Tolerates acid soils and heavy clays, no water logging
	Sesbania sesban	100-2,300	500-2,000	(10 min.) 18-23 (45 max.)	Tolerates water logging, saline, acid and alkaline soils
	Sapium ellipticum	1,000 - 2,450	(min. 1,000) 1,200-2,000	n.a.	n.a.
Exotic to Uganda	*Acacia mearnsii*	300-2,440	500-2,050	9-20	Does not tolerate alkaline and calcareous soils
	Alnus acuminate	1,200-3,800	1,000-3,000	4 to 27	Tolerates acid soils
	Calliandra calothyrsus	250-1,800	700-4,000	(20) 22-28	Tolerates infertile, compacted soil, no water logging and alkaline soils
	Eucalyptus grandis	0-2,700	100-1,800	-1-40	Tolerates well drained and water logged soils
	Glyricidia sepium	0-1,200 (1,600)	600-3,500	15-30	Tolerates marginally saline soils, no acidic soils
	Leucena leucoceophala	0-1,500 (max. 2,100)	650-3,000	25-30	Tolerates saline soils, no water logged or acid soils

Species were ranked on how well they fit the selection criteria (see section 4.2) for the target areas (see Appendix 1). Additionally, a certainty assessment is given for the pool of information used to make the ranking decision (Appendix 2). This was done because the amount and quality of information available varied widely among species.

Rankings for both criteria and certainty of information were made qualitatively. For ranking criteria, following ranks were given:

- High ranks were given when the data available on a species indicated that its performance was in the upper third of the range of all considered species;
- Medium ranks were given when the data available on a species indicated that its performance was in the middle third of the range of all considered species;
- Low ranks were given when the data available on a species indicated that its performance was in the lower third of the range of all considered species.

According to the applied SRC suitability criteria, native *Markhamia lutea* and *Sesbania sesban* scored highest with 7 and 10 criteria assessed as ‘high’, respectively (Appendix 1). The exotic species show a fairly similar distribution of high, medium, and low ranks. Future research should be focused on *Markhamia* and *Sesbania*. However, some criteria might be more relevant then others, e.g. biomass productivity might be weighted differently than intercropping potential. In addition, other uses for these species and local knowledge of their use and management would be important considerations for developing SRC systems.

Certainty plays a significant role for some categories more than others. For example, biomass productivity yields may come only from good quality sites or from small, well maintained research plots that could over represent production at a large scale. It is clear that most of the reliable information is available for the exotic species *Eucalyptus grandis* and *Acacia mearnsii* (see Appendix 2). The native *Sesbania sesban* follows closely in certainty of information as it is was introduced to other countries and research on it is done on an international scale. Although not introduced to other countries, *Markhamia lutea* is currently receiving some research attention within its native range and a useful pool of information is beginning to be developed.

5.2 Wood gasification technology at Muzizi Estate (JFU)

5.2.1 Electrical conversion efficiencies, technical and financial aspects

A dataset for a gasification system at the Muzizi Estate covering 41 days in December 2006 to January 2007 was made available for analysis by the James Finlay Ltd. Fuelwood consumption was 1.6 tons of air dried wood (15 % moisture) or 1.36 odt per MWh of electricity produced[3] (see Table 2). Considering an energy content of 18 GJ per odt of Eucalyptus wood, this equals an electrical conversion efficiency of 15 % (24.5 GJ/MWh). The total annual electricity output equals 381 MWh when using the discussed dataset as baseline.

There was one day per week where the gasifier system was not operating at all due to maintenance operations. The overall load factor, i.e. the total time the gasifier system was running, for the 41 days covered by the dataset was 50% (see Table 2). The current average power output is 87 kW, far below the rated 200 kW peak capacity rating of the system.

The heat recovery unit is located at the exhaust and cooling cycle of the syngas engine. Maximum heat recovery is assumed to be 80% of the heat produced (Back 2007). However, actual heat recovery data was not obtainable due to missing control units.

[3] At a price of 22 US$/odt, fuelwood costs equal ~0.03 US$/kWh at a 15 % conversion efficiency

The gasifier systems' atmospheric emissions contain very little if any sulfur because it is not present in wood and the CO_2 produced can be considered to be cycling in a closed loop when the fuelwood plantations are managed sustainably. Other specific air emissions from the system have not been monitored. The preliminary analysis of the dataset indicates that the system - as it is running right now - replaces ~ 120,000 liters of diesel per year, which is equivalent to offsetting 314 tons of CO_2 per year.

As seen in Table 2, total electricity production costs are 0.22 US$/kWh (including capital, operational, maintenance, and labor costs). Capital costs are 2,087 US$ per kW installed and include the feasibility study, a starter generator (30 kW), supporting infrastructure (including water pond), gasifier, syngas engine, shipping, duty, insurance, clearance, fuelwood processor, wood processing shed, installation and commissioning, additional electrical controls and training units. For the gasifier system at Muzizi Tea Estate at 87 kW production (current scenario), assuming a project and equipment lifetime of 13 years, costs associated with the systems fall into the following categories: Capital 43 %; Fuelwood and Operations (operational and maintenance costs) 29 %; Labor 28%. The gasifier system is only marginally viable economically when competing with an electricity price of 0.25 US$/kwh from subsidized diesel generators at an Internal Rate of Return of 6 %. In this case, the payback period is 9.5 years (Appendix 4). For a gasifier system at 150 kW production (future scenario)[4], competing against unsubsidized electricity derived from diesel generators (0.33 US$/kWh of which 0.32 US$ are for fuel), the IRR would increase to 18 % and the payback period would be reduced to 4.5 years (Appendix 5).

JFU expects to save 15% of fuelwood at the boiler due to the heat recovery unit at the syngas engine. However, this figure could not be quantified as key input variables were not available such as boiler efficiency, heat loss in pipes, or total heat demand.

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[4] With changing the ignition timing, an average output of > 150 kW became reality when finalizing the report in July 2007

Table 2: Analysis of status quo performance of gasifier system at Muzizi Tea Estate.

SELECTED INPUT DATA		
Fuelwood price[5]	21.8	US$/odt
Electricity price (subsidized diesel generators)	0.25	US$/kWh
Energy conversion factor	1.36	odt/MWh
Average capacity	87	kW
Load factor	50%	%
SELECTED OUTPUT DATA		
IRR	6%	%
Total capital costs[6]	459,198	US$
Total Operational and Maintenance (non-labor) costs[7] per year	23,823	US$/year
Total labor costs[8] per year	23,271	US$/year
Capital costs per kW installed	2,087	US$/kW
Electricity costs	0.22	US$/kWh
MWh produced per year	381	MWh/year
Liters of diesel saved per year	118,129	Liter/year
Fossil fuel costs saved per year	82,690	US$/year
Wood consumed	518	odt/year
Fuelwood costs	0.03	US$/kWh
CO_2 saved	314	tons/year
Electrical conversion efficiency	15%	%

5.2.2 Fuelwood supply

An economically viable gasification system for electricity production requires a sustainable feedstock supply system. In Table 3 the minimum and maximum area required for the feedstock supply is presented per kW installed. This assumes a load factor of 50%, i.e. the gasifier system is running for 50% of the time as is currently the case at Muzizi Tea Estate. Assuming low fuelwood stand production (5 odt/ha/yr) and low electrical efficiency, the gasifier would require

[5] Fuelwood costs at plant gate, including all occurring costs such as land lease, operations, transport

[6] Capital costs include: feasibility study; starter generator 30 kW; building (including water pool); gasifier; gas engine; shipping; duty, insurance, clearance; fuelwood processor; wood processing shed; installation and commissioning; additional electricity controls; and training.

[7] Operational and maintenance (non-labor) costs include: land costs, fuelwood, fuel for starter generator, maintenance material, wood hauling from stacks, top up engine overhaul every five years and major overhaul every four years.

[8] Labor costs include costs of: engineer; skilled assistant; two unskilled assistants; indirect labor costs 40%; and wood choppers.

about 1 ha/kW. In the best case scenario with high plantation yields (15 odt/ha/yr) and high gasifier efficiency (24%), the system would only require 0.2 ha/kW.

The growth figures for fuelwood plantations at Muzizi Tea Estate are rather high and can be estimated around 15 odt/ha/yr. Assuming that in future the gasifier at Muzizi Tea Estate runs at full capacity of 200 kW at 50% of the time with a 24% electrical efficiency, an additional 40 ha of fuelwood plantation would be needed (see Table 3).

Table 3: Area demand per kW installed at 50 % load for different efficiencies and growth rates.

	Wood consumption in (odt/MWh)	Electrical efficiency (%)	Stand productivity(odt/ha/yr)	Required fuelwood plantation area (ha)
'Worst' Case	1.36	15 %	5	1.0
Current situation	1.36	15 %	15	0.34
'Best' Case	0.85	24 %	15	0.2

The current wood consumption of the gasifier system of 518 odt per year (see Table 2) requires 35 ha of fuelwood plantations under this growth scenario. Considering that there are a total of 99 ha of fuelwood plantations at Muzizi Tea Estate and an estimated 70 ha are already required for the fuelwood for the boiler, the fuelwood supply issue has to be immediately addressed.

Considering impacts of exotic tree species on biodiversity, or intensive plantation management and high harvest rates on soil and hydrology, little research has been carried out at JFU or in the region it is operating. The recent outbreak of the chalcid wasp (*Leptocybe invasa*) also affected *Eucalyptus grandis* stands at Muzizi Tea Estate and raises concerns. JFU is currently interested in exploring diversification of species and varieties used in fuelwood plantations. Under closer review are *Acacia mearnsii* (nitrogen fixing, native to Australia), and *Markhamia lutea* (termite resistant, native to Uganda) both for their exceptional biomass productivity (Sandom 2007).

5.3 Community power assessment for Kyangwali

5.3.1 Current electricity demand and purchasing power assessments

During the visit to Kyangwali, the cumulative daily electricity load was assessed for both the administration of Kyangwali and the Kasonga Trading Center (Figure 6). The blue area in Figure 6 shows the current electricity demand of the administration provided by the existing generator. Currently, the electricity demand is fairly constant with a load around 3 kW during work hours.

There are several businesses including barber shops, cinemas, metal workshops, and battery charging stations in Kasonga that own and operate gasoline generators in sizes ranging from 0.6 to 1.2 kW. Depending on the business type and opening hours, gasoline consumption ranges from 2 liters/day (barber shops) to 7 liters/day (metal workshop/cell phone charging). The last column in Table 4 shows current expenditures per kWh consumed. The electricity demand for Kasonga is displayed in the purple area in Figure 6. Besides estimations on the actual electricity consumption of the aforementioned businesses, the data described in the graph also considers the projected electricity demand if all businesses along Kasonga road and adjunct homes or a total of 78 units would be wired for electrical light. Taking these consumer units into account and assuming fuel consumption as displayed in Table 4, the businesses and 78 homes of Kasonga currently spend between US$ 220 and 310 per week for energy services other than electricity (kerosene for lanterns, gasoline for generators) which could be served by a central electricity production unit.

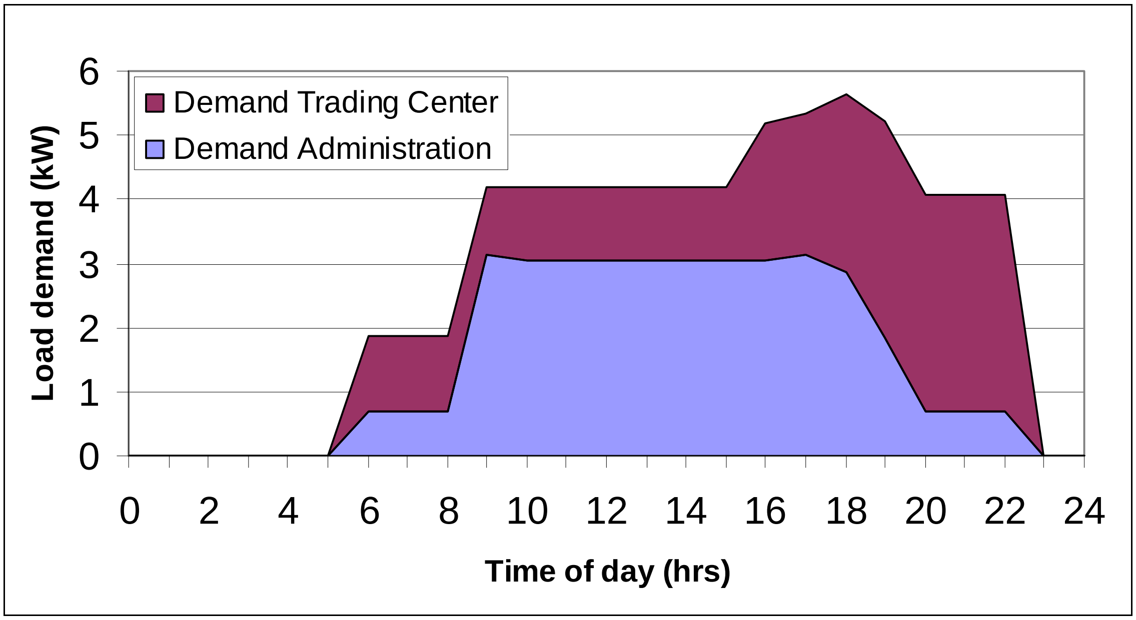

Figure 6: Cumulative daily electricity load demand assessment for the administration and Kasonga on a working day.

Table 4: Overview on current daily expenditures at Kasonga on electricity and lighting.

CONSUMER CATEGORY	REPORTED GASOLINE CONSUMPTION (L/DAY)	FUEL COSTS PER DAY (US$)	ESTIMATED ELECTRICITY CONSUMPTION (KWH)	CURRENT FUEL COSTS PER UNIT (US$/KWH)
One Barber shop	1.5 - 4	2 - 5.4	0.18 – 0.35	11.1 – 15.4
One metal workshop/cell phone charging business	3 - 7	4 - 9.5	~ 2.9	1.4 – 3.3
One cinema/cell phone charging business	4	5.4	~ 6	0.9
Lighting one room	2 candles or ~ 0.1 liter kerosene	0.11 - 0.17	0.08 – 0.1*	1.4

* when using light efficient bulbs for lighting the same rooms.

A preliminary purchasing power assessment was carried out focusing on two main areas: current business expenditures in Kasonga for i) lighting and ii) generator use. An assessment of 10 business revealed average lighting costs per evening of 0.17 US$ for both lighting with candles or kerosene. Charging a cell phone is currently offered in Kyangwali for ~ 0.28 US$. With electricity costs for generators around 0.3 US$/kWh and assuming a electricity consumption of 0.1 kWh only per charging cycle, there is sufficient purchasing capacity to pay fully for the service.

Of all businesses relying on their own gasoline generators, barber shops represent the extreme case with the highest costs per unit (see Table 4, 11.1 – 15.4 US$/kWh); expenditures for gasoline can consume up to 80 % of revenues. As they use only a fraction of the electricity produced by the generators, their gains in profit would be highest if connected to a grid and paying only for the actual electricity consumed.

5.3.2 Results from a participatory sustainability assessment

A participatory sustainability assessment was carried out with key stakeholders of Kyangwali. In a workshop setting, the sustainability of current electricity supply was analyzed based on flow models and the criteria generated by the group and compared with a potential gasification system delivering electricity. As a first step, the alternative energy systems were described as follows:

- The ‘business as usual’ (BAU) alternative, encompassing total installed capacity of 16 kW provided by 7 fossil fueled powered generators individually owned by the consumers (business and administration). It is assumed that in total two jobs are created for maintaining these generators and average electricity costs are 0.5 US$/kWh.
- The 10 kW gasification system delivers electricity to the administration buildings and Kasonga for 17 hours a day at 0.3 US$/kWh. It is supplied by fuelwood from farmers for cash. It is assumed that the bioelectricity alternative creates 9 jobs covering technical services to operate the gasifier and grid, fuelwood supply chain, and overall management.

In a second step, criteria were identified and ranked by the key stakeholders on their perceived importance. The result of this stakeholder driven process was the selection of the nine criteria shown in Table 5. Percentage numbers for each criteria describe their perceived importance.

In a third step the alternatives (fossil fuel vs. gasification) were rated. Stakeholders were asked to rate the two alternatives against each criteria in a group process. All ratings were consensus decisions with remarkable agreement between stakeholders. Moreover, Table 5 shows the priority rankings of alternatives for each criterion. The ratings were left to the stakeholders, with the exception of ‘employment and ‘cost efficiency’ in which expert input provided real numbers (jobs created and costs in US$/kWh, respectively). On the 1-9 point AHP scale, they could indicate how each alternative was perceived as superior and by how much. For further data processing, results were normalized, i.e. results from the 1-9 point scale were converted in a way that individual performance of alternatives for one criteria summed up to 1 for all alternatives. E.g. for land availability, the preference question was phrased in the following way: “On a 1 to 9 point scale, with 1 indicating absolute preference for the fossil fuel alternative, and 9 indicating absolute preference of the gasification alternative, how much do you prefer the fossil fuel alternative over the gasification alternative”. In the case of ‘land availability’, the point 2 was chosen on the 1-9 point scale which is normalized to 0.88 for the fossil fuel alternative (superior) and 0.12 (inferior) for the gasification alternative, summing up to 1. If both alternatives would have been equally preferable, the point 5 would have been chosen, weights would have been normalized to 0.5 for both alternatives. Underlined green numbers indicate superiority, red indicate inferiority. All criteria had to be maximized with the exception of ‘cost efficiency’ which had to be minimized (decreasing costs are preferable).

Table 5: Sustainability criteria ranked according to their perceived importance and rated alternatives.

RANK	SUSTAINABILITY CRITERIA	WEIGHTS	FOSSIL FUEL	BIOELECTRICITY
1.	Land availability: competition for land between food production, housing, energy, medicine, etc.	**12 %**	**0.88**	0.12
2.	Pollution: atmospheric pollution, waste water, solid waste treatment	**4 %**	0.12	**0.88**
3.	Training needs: need for capacity building, knowledge needed to run a system	**13 %**	**0.62**	0.38
4.	Employment: jobs and quality of jobs created through an energy system	**8 %**	2	**9**
5.	Ownership: who owns and controls the equipment? How does the fuelwood supply chain work? How difficult is it to encourage individual woodlots?	**13 %**	**0.89**	0.11
6.	Planning and monitoring: need for statement of objectives, carrying out inventories etc.	**18 %**	**0.63**	0.37
7.	Trade balance: impact on local trade, i.e. financial flows within community and monetary exchanges with outside community	**11 %**	0.18	**0.82**
8.	Cost-efficiency: economics of the system, return on investments	**11 %**	0.5*	**0.3**
9.	Supply security: reliability of the system including performance of technology and reliability of fuel supply	**11 %**	0.41	**0.59**

Underlined and green: superior; not underlined and red: inferior

* This cost reflects an average of the high electricity prices of Kasonga and the lower price of 0.34 US$/kWh paid by the adjacent administration buildings which were included in the hypothetical bioelectricity alternative as consumers connected to the grid.

Although the bioelectricity alternative scored higher in 5 out of the total 9 criteria and could hypothetically provide less expensive power, the total aggregated score based on the AHP methodology indicated that the current BAU is preferred over bioelectricity. Assuming 100 % satisfaction with the BAU alternative, the bioelectricity alternative reached only 89 % as it scored lower in the criteria assigned with a high weight (critical criteria) such as ‘planning and monitoring’, ‘ownership’, ‘land availability’, and ‘training needs’ (listed in decreasing order according to assigned weights). In other words, the stakeholders were very aware of the problems associated with a more complicated (bio)electricity supply system. To make bioelectricity a preferred option, this analysis suggests following conclusions:

- The decision favored the BAU alternative but was not ‘robust’; i.e. the competing (bioelectricity) alternative ranks close to the BAU alternative (89 % vs. 100 %, respectively);
- To improve overall ranking of the bioelectricity alternative, efforts have to concentrate on improving the rating of those critical criteria, particularly ones that involve interactions and coordination among community members (Training needs, Ownership, and Planning and Monitoring);
- With the exception of ‘land availability’ (an inherent disadvantage for bioelectricity compared to fossil fuel based systems), the critical criteria could be reversed favoring bioelectricity by providing the community with business models, knowledge transfer, resolving user rights, and identifying suitable management structures. Moreover, although the impact on land availability of a bioelectricity system was acknowledged, it was not perceived as a severe problem as that there seems to be still plenty of underutilized land available.

Management structures were not discussed with the stakeholders as it was seen as imperative not to raise expectations within the community. It was made clear to the stakeholders at Kasonga that this is a first pre-feasibility study and not an effort to resolve the problems identified.

5.3.3 Estimated production costs of bioenergy vs. fossil fuel based production

As mentioned above, the administration at Kyangwali currently pays 0.34 US$/kWh while inhabitants of Kasonga pay between 0.9 and 15.4 US$/kWh for selected electricity services or services that could be delivered by electricity. Therefore, any generation system that can produce below this cost is advantageous under a financial point of view.

Based on an initial financial analysis, the gasification system is economically viable and an attractive alternative to the diesel and gasoline generators when excluding interest payments on capital costs. It could produce electricity at 0.23 US$/kWh (see Table 6). When pricing electricity at 0.3 US$/kWh from the gasifier system, the project earns an Internal Rate of Return 12 % while offering cheaper electricity to Kasonga and the administration compared to the current situation. These costs include grid connection cost of businesses operating currently with generators and the connection of an additional 72 units which currently have no access to electricity for lighting and small appliances (e.g. radios).

The capital costs are close to 50% of the total cost of the system. From a financial perspective, this high up-front investment can be justified by the low operational costs, i.e. fuel costs of 0.3 $/kWh. Approximately 700 US$ would be spent on fuelwood every year; a potential source of additional income for farmers if a community based forestry scheme was used. Labor costs to operate the system – which are often used to argue against gasification when compared with diesel fueled power production – account for only 14% of total costs. The payback period is around 6 years (see Appendix 6). All figures are given for a project lifetime of 10 years and do not include cost of capital as it is assumed that a potential pilot project would need to draw on favorable project financing schemes such as grants.

Although being financially viable in theory, the project’s high startup costs, exclusion of interest payments on capital costs, and the payback period of several years are a significant obstacle for its implementation considering the low capital accessible by the community and its lack of financial experience managing a project of this size. Providing a favorable project financing scheme and financial advice is considered to be crucial to establish a successful pilot project at Kasonga which could then be replicated in other rural areas.

Table 6: Input and output figures for the gasifier system producing 4 kW for 17 hours a day.

PHYSICAL AND FINANCIAL KEY FIGURES		
Investment costs gasification system	2,700 (27,000 total)	US$/kW
Investment costs grid connection	5,300	US$
Fuelwood price paid	18.5	US$/ton*
Electricity output	4	kW
Load factor	17	Hours/day
Electricity selling price	0.3	US$/kwh
Depreciation period	10	years
Internal Rate of Return (IRR)	12 %	%
Electricity costs	0.23	US$/kWh
Fuelwood costs	0.03	US$/kWh
Fuelwood supply	107	kg*/day

* air dried at 15 % moisture

6 CONCLUSION AND RECOMMENDATIONS

6.1 SRC species as feedstock

There is no single SRC species based on the currently available information that stands out for use as input into a bioenergy system in Uganda. Suitability of species depends on many factors specific to a site such as biophysical limits or available knowledge on and acceptance for a species. However, in this report, we attempt to identify species which are promising and should be considered for further investigations. We also recommend that a number of different species be investigated and developed to ensure that diversity is maintained in SRC systems.

The most reliable information is available for *Acacia mearnsii, Eucalyptus grandis, Sesbania sesban,* and *Markhamia lutea*. Besides ranking highest in certainty of information, these four species also received high rankings in their suitability for SRC applications. Research on *Markhamia* just started recently; *Eucalyptus* and *Sesbania* have more extensive research records. The native *Sesbania* is promising as a SRC species and could help to diversify the dominance of *Eucalyptus* plantations. *Sesbania* is an attractive alternative due to its high biomass productivity, wide acceptance and nitrogen fixing abilities. Besides being native to Uganda, *Markhamia* is a promising species for its pest and disease resistant nature (e.g. not prone to termites) and ranks high in the criteria assessment ignoring the certainty of information. Despite being of exotic origin in Uganda, *Acacia mearnsii* should be considered especially for drier sites and is increasingly seen as an alternative to *Eucalyptus* also for large industrial plantations (Sandom 2007) under increasingly frequent weather extremes.

To further identify and unfold the potential for bioenergy through SRC plantations in Uganda, we recommend the establishment of mixed and single species trials with aforementioned species, in collaboration with local partners from research such as the Centre for Research on Energy and Energy Conservation (CREEC) and potentially interested communities, industrial users, or investors on various sites and locations in Uganda.

6.2 Improvements needed for replication of gasifier technology installed at Muzizi Estate

The wood gasification system commissioned in 2006 at Muzizi Estate is rated at 200 kW electrical capacity and was installed to substitute a diesel generator with the same rating to reduce electricity production costs. To allow replication of the wood gasification system installed at Muzizi Estate, the current performance of 87 kW average power output is far below expectations[9]. For improvement and/or replication of the system, the following issues need to be addressed:

- The gasifier system has only been able to produce 150 kW on a constant basis, not the 200 kW it is rated for. Although there are serious efforts on behalf of JFU to reach the rated capacity, the identification of the problem is difficult due to a lack of control and monitoring units measuring gas pressure, gas composition, air leakage, or temperatures.
- Although the gasifier system has proven to be able to produce 150 kW on a constant base, it is only running at 87 kW due to a problem in the design of the electrical system. Under the current layout, the gasifier system is only connected to the withering troughs with a low average load. Ideally, the electrical system should be designed in such a way that the gasifier system would provide a stable base load producing at its maximum capacity. Furthermore, it can be expected that the overall current electrical efficiency of the gasifier system of 15% can be improved by approaching the rated capacity of the system.
- Additionally, the withering troughs are characterized by a highly variable[10] load. Turning on or off of only one trough out of 34 results in sudden demand changes of 10 kW. Highly variable loads result in retarded changes in gas pressure not matching demand in the syngas engine and leading eventually to a shut down. Ideally, the electrical system should be designed in such a way that the gasifier system would provide a stable base load. Peak loads would be served by diesel generators.
- Operating the gasifier far below its current maximum stable output capacity of 150 kW severely restricts the time that is available for analysis of the technical causes. Only by operating the gasifier at its current maximum potential 150 kW, is it possible to identify the underlying causes and stepwise increase output by eradicating them.

6.3 Kyangwali socio-economic and power demand assessment

The administration buildings at Kyangwali and the adjacent Kasonga Trading Center already have an electricity system powered by individual gasoline generators. This electricity supply system is expensive to run and maintain and in many cases inefficient. At the same time, the Kasonga Trading Center and the various administrative institutions possess the purchasing power to buy extended electricity services; in addition, fuelwood plantations for supplying a potential bioenergy system are in place and land is available. As shown in Table 5, a bioenergy system serving both the administrative buildings and Kasonga Trading Center would be preferable in terms of employment (9 jobs created as part of the bioelectricity alternative vs. 2 jobs created in the fossil fuel alternative) and local trade balance (currently between 220 and 310 US$ are spent on fossil fuels each week). The bioelectricity alternative could provide cheaper electricity services to more people than is currently the case and is perceived as the alternative with an higher electricity supply security.

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[9] With changing the ignition timing, an average output of > 150 kW became reality when finalizing the report in July 2007

[10] Defined here as changes in power demand of > 5 kW within 2 minutes

Stakeholders are actively involved in developing the community and have an impressive project track record. The workshop outcomes and a first preliminary and participatory Multi-Criteria Analysis using the Analytic Hierarchy Process provided valuable insights in how stakeholder perceived the competitive advantage of a bioelectricity alternative compared to the current energy situation. It could be concluded that efforts would have to concentrate on business models, resolving user rights, identifying suitable management structures, and knowledge transfer in order to resolve the community's concerns.

Kasonga Trading Center provides above average conditions which are necessary for a pilot project but is still representative to a large degree for other rural communities in Uganda. However, to install a small-scale bioenergy pilot project that – if successful - could be replicated many times in rural Uganda and beyond, Kasonga Trading Center with the adjacent administration buildings would need considerable support initially in developing its social capacity.

On the bioelectricity production side, the technology is being tested in Uganda, and adapted to the conditions of rural Africa. Experiences from rural India indicate that gasification can be a competitive source for rural electricity. However, to install and maintain such a system, support has to be provided to the entity running the system. Applied research institutions such as the Center for Energy and Energy Conservation (CREEC) at Makerere University have the capacity to build a network and provide support for such distributed bioelectricity systems. From a technical perspective, Kyangwali has the capacity to run such a bioelectricity system. Technically versed labor and organizational skills are in place, but will require some training to make the system successful.

6.4 Barriers for a broad implementation of bioelectricity

The analysis of the gasifier system at Muzizi Tea Estate showed that gasification could be an economically attractive alternative to diesel generated electricity for rural agroindustry under certain conditions. Also, the BIOSYRCA project identified five main components that would require additional attention to ensure the successful implementation of a gasification system in a wider range of areas.

High capital costs

Although running on a potentially inexpensive fuel (woody biomass at 0.03 US$/kWh at Muzizi Tea Estate), gasification systems are characterized by high capital costs (2,087 US$/kW at Muzizi Tea Estate; 2,700 US$/kW estimated for Kasonga). Such high upfront costs and long payback periods are a bottleneck for rural electrification efforts beyond large agroindustrial operations unless supportive project financing schemes are in place. Interest payments for capital costs were not considered in this study.

Capacity building and viable business models

The case study at Muzizi Tea Estate clearly shows the need for well designed business models to manage the feedstock supply, conversion technology, and energy allocation components of a gasification system. Such requirements go far beyond the capacities of the usual family businesses that are present in Kyangwali. This primarily includes ownership issues like who would own the business and carry the responsibilities, the need for technical training as well as planning and monitoring skills like financial and managerial skill training and - given high startup costs and a payback period of several years, a favorable project financing scheme needs to be made available for a pilot project. Determining who could initiate and maintain such schemes (governmental agencies, NGOs, development agencies) has to be addressed in future studies.

In order to make a pilot project successful and demonstrate the potential of these bioenergy systems over the long term, institutionalized project financing schemes with favorable terms would need to be in place. However, without reliable business models, investors will not take the risk to invest in respective systems. The creation and support of Energy Service Companies (ESCOs, Vine 2005) could serve this end. The concept of an ESCO managing the feedstock supply, conversion technology, and energy allocation as a non-regulated entity is an existing business model which might be suitable for this application. ESCOs do not exist yet in Uganda but lessons learned from other developing countries (Ellegård et al. 2004, Lee et al. 2003) can be considered in the design. Questions like not-for profit and/or cooperative setups vs. for-profit and/or private setups have to be raised. Therefore, considerable public and private research and capacity building is required to develop and promote respective business opportunities and to overcome existing barriers such as the high capital costs for gasifier systems. Future studies have to focus on business models and financing schemes.

Economic viability of wood-based electricity systems also depends to a large degree on its comparative advantage to other markets of electricity production, be it from renewable sources or fossil fuel based systems. These other options, especially the use of individual solar panels for low consumption use like lighting or charging cell phones, need to be explored to determine if they are more viable solutions than a community based gasification system.

Stable loads

Part of a viable business model is to match the system capacity to the power demand. High peak loads and abrupt power demand changes can be avoided or buffered already in the planning stage of such electricity systems.

Sustainable fuelwood supply chains

Business models for a complete gasification system have to provide incentives for farmers and entrepreneurs to provide biomass, all year round and from sustainable sources. This can be achieved either by fuelwood sources managed directly by the electricity provider or by community based forestry schemes encouraging farmers in SRC or plantation establishment and maintenance in order to grow fuelwood and sell it to the group operating the conversion unit. This approach would allow for additional income generation for farmers and spread revenues more equally. However, to ensure a sustainable source of fuelwood, such a scheme would require significant efforts for a pilot project, such as clear user rights or establishing a committed SRC/agroforestry/forestry extension service covering training, quality monitoring, and/or provision of material and considerable preparation time of several years to ensure a fuelwood supply from well established and managed systems. Unmanaged on-farm trees and agricultural residues are usually not sufficient or sustainable. The fuelwood for the gasifier could be supplied by SRC systems; assuming a medium stand productivity of 10 oven dried tons/ha/year, 8 ha would be sufficient for a sustainable supply. The bioenergy system would need ~ 92 kg of air dried wood daily or 1.3 m^3 per week.

Issues like competition with food production, fuelwood for cooking, biodiversity, site protection, or forest health would have to be addressed. If there was a degree of local control among all the components of the system – fuelwood supply, conversion technology, and power distribution, it is more likely that a gasification system would be successful in rural electrification projects and be fed from a sustainable fuelwood source. Any approach to developing wood production systems to provide biomass for gasification needs to consider other local or regional conditions including local market studies on demand for wood products for other end uses such as building poles, fuel for manufacturing processes, charcoal and firewood. Opportunities to produce multiple products from SRC or fuelwood systems should be explored in order to optimize benefits and reduce the level of risk for landowners involved in such a system.

Species trials with promising SRC species

The precarious availability of information especially on native species suggests the need i) to establish mixed and single species trials with species such as *Markhamia lutea*, *Sesbania sesban,* but also the exotic *Acacia mearnsii* in collaboration with local organizations such as the Centre for Research on Energy and Energy Conservation (CREEC) and potentially interested communities, industrial users, or investors on various sites and locations in Uganda. and ii) to intensify identification and measurements of existing plantations of these and other species.

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9 APPENDIX

Appendix 1: SRC species **ranking according to criteria** for site conditions prevailing at Muzizi Tea Estate and Kyangwali.

	NATIVE SPECIES			EXOTIC SPECIES					
	MARKAHMIA LUTEA	SESBANIA SESBAN	SAPIUM ELLIPTICUM	ACACIA MEARNSII	ALNUS ACUMINATA	CALLIANDRA CALOTHYRSUS	EUCALYPTUS GRANDIS	GLYRICIDIA SEPIUM	LEUCENA LEUCOCEOPHALA
Biomass productivity	M	H	L	H	M	H	H	M	M
Survival capacity	H	H	M	M	M	M	M	M	M
Ecosystem integrity	H	H	H	M	M	M	M	M	M
Propagation	H	H	M	H	H	H	H	H	L
Maintenance	H	H	M	H	M	M	M	M	M
Growth shape	H	H	M	H	H	H	H	H	H
Fuelwood quality	H	H	M	H	H	H	H	M	H
Intercropping potential	M	H	H	M	H	M	L	H	H
Local acceptance	H	H	M	M	L	M	H	L	L
Non timber products	M	H	M	M	L	M	L	H	H
Total H	7	10	2	5	4	4	5	4	4
Total M	3	0	7	5	4	6	3	5	4
Total L	0	0	1	0	2	0	2	1	2

Comments: H=High; M=Medium, L=Low

Appendix 2: Ranking **certainty of information** on SRC species for site conditions prevailing at Muzizi Tea Estate and Kyangwali.

	Native Species			**Exotic Species**					
	Markahmia lutea	**Sesbania sesban**	**Sapium ellipticum**	**Acacia mearnsii**	**Alnus acuminata**	**Calliandra calothyrsus**	**Eucalyptus grandis**	**Glyricidia sepium**	**Leucena leucoceophala**
Biomass productivity	M	H	L	H	M	M	H	M	M
Survival capacity	M	H	L	H	L	L	H	M	M
Ecosystem integrity	M	M	L	H	L	M	H	M	M
Propagation	M	M	L	H	M	M	H	M	M
Maintenance	M	M	L	M	L	M	H	M	M
Growth shape	M	H	L	H	M	M	H	M	M
Fuelwood quality	H	H	M	H	M	M	H	H	M
Intercropping potential	M	H	M	M	M	M	H	M	M
Local acceptance	H	M	M	M	L	M	H	L	L
Non timber products	M	H	L	H	M	M	H	M	M
Total H	2	6	0	7	0	0	10	1	0
Total M	8	4	3	3	6	9	0	8	9
Total L	0	0	7	0	4	1	0	1	1

Appendix 3: Bioenergy system description and operational aspects at Muzizi Estate, JFU.

JFU replaced one of its diesel generators at its Muzizi Tea Estate with bioenergy system as a pilot project to offset its diesel fuel costs. This project was designed to determine if it would be wise to make similar substitutions at its other tea estates. To date, JFU speaks of 'minor problems' with this pilot project and is still pursuing replication on other estates. The system is based on wood gasification; the gas produced is cooled, cleaned and runs a syngas engine to produce electricity. The pre-feasibility study, system design and choice of manufacturer for the gasifier system was carried out in 2005. The gasifier system was installed and commissioned in May 2006 and has been running consistently since August 2006. It is the first application that we are aware of using gasification technology in scales > 10 kW in East Africa.

Fuelwood logistics chain

Currently the fuelwood demand, primarily for tea drying[11], at the Muzizi Tea Estate is covered by 99 ha of internally owned and managed fuelwood plantations consisting of *Eucalyptus grandis* in plot sizes ranging from 2 to 8 ha (Figure 2). Trees are grown from seeds of different origin (South Africa, Kenya, Zimbabwe) in an onsite nursery. Seedling were planted by employees in a spacing from 3x1.5, 2.5x2.5 and most recently 3x2.5 (1,300 to 2,200 trees/ha). Establishment steps include site clearing and removing of vegetation, laying out of planting lines, pitting holes for the plantss, contact herbicide application (1.5 l glyphosate per ha), planting, and manual weeding every second month in the dry season or every month in the wet season totaling 6 to 10 weeding operations per stand. Previously stands were replanted after harvesting, but since May 2006, replanting is not occurring, but coppice regrowth is being encouraged on a trial base.

Except for yearly stand inventories (randomized plot samples) and pest monitoring, there are no maintenance operations scheduled. Inventories and estimates on the mean annual increment (MAI) range from 10 to 40 oven-dried tons[12]/ha/yr (Sandom 2007, James Finlay Uganda 2007).

Figure 7: Harvest and transport operations in a 7 years old *Eucalyptus grandis* stand at Muzizi Tea Estate; coppicing *Eucalyptus grandis* stumps in foreground.

In 2006, 15 ha of stands aged 7 to 11 years old were harvested. The mean diameter at breast height (DBH) was 17 to 20 cm. Harvest and transport operations include manually cutting the underbrush, felling the trees with chainsaws, debranching with machetes[13], bucking the stems into one meter long sections using chainsaws, splitting these sections with wedges, manually moving the split sections to the road side, and hauling the material on a truck 0.7 to 2 km to the tea factory. At the factory the wood is stacked outside and air dried down to a moisture content of around 15 % which can be reached under the local conditions within 6 months. At the date of the visit, there was a total of about 850 odt stacked wood which was expected to last for ~6 months.

Harvest, transport, and stacking of wood is outsourced for ~13 US$/odt. Total fuelwood costs including establishment, maintenance, harvest, transport, and stacking are estimated to be around 22 US$/odt (see Table 2).

Figure 8: Debranching with machetes, cutting meter sections with chainsaw.

Figure 9: Eucalyptus coppice after 9 months after cutting.

The stacked and dried meter sections of fuelwood are cut into 10 cm x 10 cm x 10 cm billets by aide of a circular saw and a hydraulic splitter ready to be fed into the gasifier (Figure 10).

Figure 10: Billet preparation with circular saw and hydraulic splitter combination.

Figure 11: Wood billets in the gasifier feeder.

Power conversion system

The power conversion system is the GAS 250 system from Ankur Scientific, India. It is rated at 200 kW net electricity output and is installed in a shed measuring 10 m x 20 m, which does not include wood storage and water cooling pond. The GAS 250 conversion system includes the following parts (Figure 4):

- A downdraft gasifier reactor from Ankur Scientific, India rated at 400 kW thermal output with automated fuelwood feeder and water flushed ash and charcoal removal.
- A cyclone filter separating ash from the hot gas (not shown in Figure 4).
- A gas cooling and scrubbing unit operated by water flow.
- Two parallel filter units consisting each of a coarse filter (wood chips) and two fine filters (sawdust, not shown in Figure 4) to allow constant operations also during cleaning of filters.
- One cloth bag filter (not shown in Figure 4).
- A blower to move the syngas to the engine.
- A 250 kW Cummins India syngas engine.
- Heat recovery units at the exhaust pipes and the water cooling cycle of the engine.
- A water cooling cycle for the gasifier circulating ~ 20 m^3 water through a cooling pond.

Figure 12: The filter line and WBG 400 gasifier at Muzizi Tea Estate.

Figure 13: 250 kW syngas engine with heat exchanger at Muzizi Tea Estate.

Electricity system and power distribution

The gasifier system is started by a generator set delivering at least 30 kW to run the critical appliances of the system (pumps, blower, fuelwood feeder, control units, etc.). Start up time is about 7 minutes when cold but considerably less when there is still hot material in the reactor. The system provides three phase electricity.

Currently, the gasification system is started by a 100 kW diesel generator on a daily base, it runs for approximately 12 hours per day continuously supplying the withering troughs only. When in operation, the electricity demand of the troughs ranges usually between 50 to 170 kW with high short term load variations.

Figure 14: Withering troughs with blowers at Muzizi Tea Estate; moisture content of tea is reduced to 70 % within ~ 12 hours.

Appendix 4: Cash flow for gasifier at 87 kW production (current scenario) at Muzizi Estate, JFU, excluding interest payments on capital costs.

Project year	1	2	3	4	5	6	7	8	9	10	11	12	13	**Total**
Capital costs														**459,198**
Feasibility study	40,000													40,000
Starter generator 30 kW	21,000													21,000
building (including water pool)	30,000													30,000
Gasifier	99,651													99,651
Gas engine	129,547													129,547
Shipping	10,000													10,000
Duty, insurance, clearance	10,000													10,000
Fuelwood processor	30,000													30,000
Wood processing shed	5,000													5,000
Installation and commissioning	40,000	20,000												60,000
Additional electricity controls	20,000													20,000
Training (Andrew to India)	4,000													4,000
Operational and Maintenance costs (non-labor)														**309,704**
Land costs*	1	1	1	1	1	1	1	1	1	1	1	1	1	17
Fuelwood**	11,305	11,305	11,305	11,305	11,305	11,305	11,305	11,305	11,305	11,305	11,305	11,305	11,305	146,961
Fuel for starter generator	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	20,693
Maintenance material	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,001	78,001
Wood hauling from stacks	1,464	1,464	1,464	1,464	1,464	1,464	1,464	1,464	1,464	1,464	1,464	1,464	1,464	19,032
Top up engine overhaul		5,000				5,000				5,000				15,000
Major overhaul				10,000				10,000				10,000		30,000
Labor costs														**302,529**
Engineer	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	176,271
assistant skilled	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	17,627
2 assistants unskilled	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	17,627
indirect labor costs 40%	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	84,610
wood choppers	492	492	492	492	492	492	492	492	492	492	492	492	492	6,394
Revenues (cost savings)														**1,238,445**
Electricity	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	1,238,445
Total revenues (cost savings)	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	95,265	**1,238,445**
Total costs	482,831	68,633	43,633	53,633	43,633	48,633	43,633	53,633	43,633	48,633	43,633	53,633	43,634	**1,071,432**
Gross margin	-387,566	26,632	51,632	41,632	51,632	46,632	51,632	41,632	51,632	46,632	51,632	41,632	51,631	**167,013**
Accumulated CF	-387,566	-360,935	-309,303	-267,671	-216,040	-169,408	-117,776	-76,144	-24,513	22,119	73,751	115,382	167,013	**-1,551,090**
Present Value (PV)	-387,566	25,124	45,952	34,955	40,897	34,846	36,398	27,687	32,394	27,601	28,831	21,931	25,659	-5,290

* ‘Land costs’ include costs for the area covered by the shed and the wood stacks

** Fuelwood costs are ‘at plant gate’ including all forest operations, land lease, and transport

Appendix 5: Cash flow for gasifier at 150 kW (future scenario) at Muzizi Estate, JFU, excluding interest payments on capital costs.

Project year	1	2	3	4	5	6	7	8	9	10	11	12	13	**Total**
Capital costs														**459,198**
Feasibility study	40,000													40,000
Starter generator 30 kW	21,000													21,000
Building (including water pool)	30,000													30,000
Gasifier	99,651													99,651
Gas engine	129,547													129,547
Shipping	10,000													10,000
Duty, insurance, clearance	10,000													10,000
Fuelwood processor	30,000													30,000
Wood processing shed	5,000													5,000
Installation and commissioning	40,000	20,000												60,000
Additional electricity controls	20,000													20,000
Training (Andrew to India)	4,000													4,000
Operational and Maintenance costs (non-labor)														**429,913**
Land costs	2	2	2	2	2	2	2	2	2	2	2	2	2	23
Fuelwood	19,491	19,491	19,491	19,491	19,491	19,491	19,491	19,491	19,491	19,491	19,491	19,491	19,491	253,381
Fuel for starter generator	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	1,592	20,693
Maintenance material	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,001	78,001
Wood hauling from stacks	2,524	2,524	2,524	2,524	2,524	2,524	2,524	2,524	2,524	2,524	2,524	2,524	2,524	32,815
Top up engine overhaul		5,000				5,000				5,000				15,000
Major overhaul				10,000				10,000				10,000		30,000
Labor costs														**302,529**
Engineer	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	13,559	176,271
assistant skilled	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	17,627
2 assistants unskilled	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	1,356	17,627
indirect labor costs 40%	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	6,508	84,610
wood choppers	492	492	492	492	492	492	492	492	492	492	492	492	492	6,394
Revenues (cost savings)														**2,135,250**
Electricity	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	2,135,250
Total revenues (cost savings)	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	164,250	**2,135,250**
Total costs	492,078	77,880	52,880	62,880	52,880	57,880	52,880	62,880	52,880	57,880	52,880	62,880	52,881	**1,191,640**
Gross margin	-327,828	86,370	111,370	101,370	111,370	106,370	111,370	101,370	111,370	106,370	111,370	101,370	111,369	**943,610**
Accumulated CF	-327,828	-241,458	-130,088	-28,718	82,652	189,021	300,391	401,761	513,131	619,501	730,871	832,241	943,610	**3,885,087**
Present Value (PV)	-327,828	81,481	99,119	85,112	88,215	79,486	78,511	67,417	69,875	62,960	62,188	53,400	55,347	**555,284**

Appendix 6: Cash flow diagram for a 10 kW gasifier system serving the administration and Kasonga Trading Center, excluding interest payments on capital costs.

	1	2	3	4	5	6	7	8	9	10
Gasifier w/o diesel engine	18,000									
Shipping, installation and commissioning, and training	7,000									
Shed	2,000									
Spare parts	700	700	700	700	700	700	700	700	700	700
Fuelwood *	728	728	728	728	728	728	728	728	728	728
Labor **	814	814	814	814	814	814	814	814	814	814
Grid ***	5200	200	200	200	200	200	200	200	200	200
Revenue	7,518	7,518	7,518	7,518	7,518	7,518	7,518	7,518	7,518	7,518
Total costs	34,441	2,441	2,441	2,441	2,441	2,441	2,441	2,441	2,441	2,441
Gross margin	-26,923	5,077	5,077	5,077	5,077	5,077	5,077	5,077	5,077	5,077
Accumulated CF	-26,923	-21,846	-16,769	-11,693	-6,616	-1,539	3,538	8,615	13,692	18,768
Present Value (PV)	-26,923	4,615	4,196	3,814	3,468	3,152	2,866	2,605	2,368	2,153

* at a current fuelwood price of US$ 18.5 per air-dried ton

** 2 employees, 150,000 USh/month plus 40 % other labor costs

*** 78 housing units connected in total, always one connection for 3 units, each connection US$ 200