Bioenergy for Sustainable Energy Access in Africa

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Technology Country Case Study Report
(incorporating Country Scoping Reports)

Submitted to DFID
by LTS International Limited, the University of Edinburgh and E4tech

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Acronyms

BSEAA	Bioenergy for Sustainable Energy Access in Africa
DFID	Department for International Development
ORC	Organic Rankine Cycle
SOGAS	*Société de gestion des abattoirs du Sénégal*
SSA	Sub-Saharan Africa
TVC	Technology Value Chain
UNIDO	United Nations Industrial Development Organisation

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Acknowledgements

This phase of the Bioenergy for Sustainable Energy Access in Africa study included visits to 18 operational energy installations in seven countries, which depended for their success on the cooperation of many people outside the core research team. We are indebted to the project developers, technology providers, operating staff and independent specialists who kindly provided background information, facilitated our meetings and visits, adapted their programmes to suit our ever-changing schedule and freely provided facts, figures and opinions. The willingness of so many people to contribute to the success of the research is sincerely appreciated. They are named individually in the mission itineraries annexed to this report.

Matthew Owen (LTS International) and Ralph Ripken (E4tech)
on behalf of consortium partners

Executive Summary

Introduction

LTS International, the University of Edinburgh and E4tech are implementing Phase I of the Bioenergy for Sustainable Energy Access in Africa (BSEAA) study. BSEAA is investigating opportunities and challenges for the roll-out of bioenergy technology in Sub-Saharan Africa (SSA) and supporting the development of innovative solutions.

Iterative phases of literature review, stakeholder mapping and technology value chain prioritisation led to the shortlisting of anaerobic digestion, gasification and combustion-based steam turbines as the most promising bioenergy technologies for BSEAA-supported research and innovation. During the Case Study phase of the assignment, a sample of representative installations was visited and desk research was conducted on steam turbines for heat or power production at sub-1 MW scale.

This Case Study Report draws upon these experiences to highlight the main barriers and opportunities for wider adoption of anaerobic digestion, gasification and small-scale steam turbines in SSA, and to identify potential research themes for Phase II.

Methodology

From a database of 153 anaerobic digestion and gasification projects in SSA, a sample of Case Studies with heat and/or power output between 10 kW_e and 5 MW_e was selected based on location in priority countries, current or recent operation, operator welcome and accessibility. Visits were organised to 18 qualifying sites (12 biogas plants and 6 gasifiers) in seven countries. Applying a standard checklist, the aim at each site was to identify barriers to replication that DFID-supported research could potentially address. Each visit resulted in an illustrated Case Study Report.

The country visits gave an opportunity to meet local experts to gather contextual information and supporting opinions. Team members also attended the ECOWAS/GBEP Bioenergy Week in Ghana, a consultative meeting with the German Biogas Association in Munich and the World Biogas Expo in Birmingham.

Visits to biomass-based steam turbine installations were not feasible as no small-size plants could be identified. Parallel desk research was instead carried out into sub-1 MW steam turbines to identify potential research and innovation opportunities.

Identified Barriers

Anaerobic digestion

Three of the profiled biogas projects are technically and commercially successful, showing that viable ventures can be developed and operated in SSA under the right conditions. The barriers experienced by developers fall into six categories.

Barrier 1: Unreliable feedstock supply

All of the successful biogas projects have sufficient feedstock on-site as a by-product of the developer's own business or an adjacent business with an equity stake. There was no successful example where the primary feedstock was being brought in from elsewhere. Novel feedstocks (e.g. lignocellulosic materials or dryland plants) may represent a breakthrough in expanding the range of feedstock options for SSA.

Barrier 2: Costly and insufficiently adapted technology

The high cost of European and North American biogas systems is a barrier to investment in SSA. Technology transferred without modification may also prove inappropriate for local operating conditions. For replication beyond well-resourced agribusinesses, cheaper designs are needed – potentially from Newly Industrialised Countries - that are adapted to the local context.

Barrier 3: Limited operator technical capacity

Insufficient operator capacity has in some cases led to technical problems such as incorrect substrate temperature, pH, solids content or microbiological conditions. Systems have under-performed or broken down as a result. There is a need to elevate skill levels through standardised training and operational exposure.

Barrier 4: Lack of viable business models

A number of factors are resulting in unviable business models. Besides insecurity of feedstock supply, they include reliance on a sole income stream, which is rarely a viable biogas strategy in SSA; and insufficient financial engagement of project owners, resulting in commercially unrealistic models. Projects fully funded by donor grants have encountered viability problems. There is a need to prioritise sites that allow valorisation of multiple outputs. Given also the lack of commercial financing for biogas in SSA, donor resources need to be applied more strategically.

Barrier 5: Unfavourable policy and regulation

Most early developers of biogas projects target captive heat and power demand within agri-businesses. Replication beyond captive sites requires a supportive framework of government incentives, such as attractive feed-in tariffs and fair access to the grid.

In many SSA countries, environmental regulations are not enforced and polluters may face no penalties for waste dumping. This makes investment in biogas less economically attractive as a waste clean-up technology.

Barrier 6: Limited access to manufacturer support and spare parts

Only one European biogas technology provider has permanent representation in SSA, so plant managers must usually be self-contained with their own in-house personnel. Lack of local support and poor access to spare parts dis-incentivises further uptake of the technology.

Gasification

The developers of the six profiled gasification projects have encountered significant barriers that make replication very challenging. The four community-based plants have been mothballed due to poor commercial viability or technical problems, the fifth is dormant due to lack of feedstock and the sixth has yet to be commissioned due to gas cleaning problems.

Barrier 1: Feedstock quality and availability constraints

Sensitivity to feedstock specifications means that gasification is an inflexible technology, which limits the potential feedstock range and supply-side adaptability.

Barrier 2: Technology limitations

Operating parameters must adhere to precise manufacturer specifications or high outputs of char, tar and particulate matter may cause cleaning problems, result in engine failure and generate an excess of toxic by-products. Small-scale gasification also lacks the same degree of power despatchability as other energy technologies, requiring a gas storage system or battery bank.

Barrier 3: Lack of viable business models

Anchor customers are often lacking in the profiled projects, none valorise heat or char and all were financed to some extent with donor funds. These factors have resulted in commercially unrealistic models and often led to over-sized systems.

Barrier 4: Limited operator technical capacity

It is challenging to secure the skills required to operate gasification systems in rural locations. There are few qualified individuals who can operate and maintain them successfully, compounding the problem of reliability and reputation.

Barrier 5: Poor access to manufacturer support and spare parts

All gasification equipment is imported to Africa and only one supplier is represented on the continent, resulting in limited access to technical support or spares. The absence of technical back-up further degrades the reputation of gasification.

Sub-1 MW Steam Turbines

The study confirmed the poor efficiency of steam turbines compared to alternative technologies at sub-1 MW output levels, for inherent technical reasons. There may still be opportunities to retrofit steam turbines for CHP in agri-businesses with an existing heat generation system and significant electricity demand in countries with high electricity costs (e.g. Kenya, Rwanda and Ghana).

Potential Opportunities

Context and Scope

Phase II research is expected to respond to the identified challenges facing the deployment of bioenergy in SSA by identifying, testing and piloting appropriate solutions. It is understood that the emphasis will be on those barriers for which research can offer particular value over other types of intervention, and that research which addresses technological barriers will be prioritised.

In defining the limits of the anticipated Phase II call, the team proposes a focus on **anaerobic digestion**. The Case Study phase has confirmed the growing commercial investment in SSA's biogas sector, to which DFID could add impetus through targeted research. The technology has high adoption levels outside the continent from which to draw lessons and leapfrog technologically, and offers significant feedstock flexibility across diverse waste streams, despatchability of the energy produced and co-benefits from environmentally beneficial waste disposal and fertilizer production.

It was meanwhile noted in the TVC Prioritisation Report that **gasification** has a poor track record at small output scales and that state of the art systems are complex to maintain, while simpler technologies are polluting and unreliable. Failure rates in SSA are close to 100% due to problems with gas quality, lack of operator expertise and spare parts, and absence of economic viability. Case study research into the small number of plants in SSA has confirmed this discouraging prognosis. The barriers to replication, in particular in small-scale community settings, are so significant and wide-ranging that there is no realistic opportunity for research to make a difference to replication potential and it is not proposed that gasification-related research is supported in Phase II.

Desk research into the technical and economic feasibility of sub-1 MW heat or power applications from **steam turbines** reveals potential for retrofitting for CHP at plants with a functioning heat generation system and significant electricity demand. Further feasibility research on this theme is a supplementary option for Phase II.

Potential research themes

Assuming a focus on anaerobic digestion, examples of potentially relevant research themes for Phase II are offered below. An open call would generate many others.

Barrier 1: Unreliable feedstock supply

Investigation into biomass resources across the prioritised BSEAA countries to quantify available feedstocks by identifying concentrated sources under clear ownership, evaluate suitability (including combinations where available) and elaborate business models for their application in biogas systems. Feedstocks could include by-products from agriculture, agro-industry, livestock and municipal waste

systems, as well as wild-harvested biomass, and might be seasonal. Such research could build on existing resource studies for specific African countries.

Exploration of the biogas productivity potential of novel feedstocks and feedstock blends, particularly those unique to Africa. Biomass from marginal drylands could be particularly interesting, including CAM plants. Social and environmental implications would need to be considered, including potential competition with existing uses and food production.

Technical and commercial feasibility assessment of methods for breaking down lignocellulosic feedstocks for anaerobic digestion, to expand the volumes of biomass potentially available for use in African biogas systems and increase biogas yields (taking into account competing uses and values).

Barrier 2: Costly and insufficiently adapted technology

Development of modified versions of European biogas technology to achieve cost reduction through design adaptation, while retaining functionality and reliability, to increase affordability and adoption rates in SSA. This should include customisation to suit African regional climates, seasonality differences, feedstock variation and other operating realities, to increase appropriateness and performance. Standardised African plant designs may result for particular feedstocks and operating environments.

Barrier 3: Limited operator technical capacity

Research into structures that could enhance interaction and mutual support between biogas plant operators, to establish a core of technical expertise for operating modern industrial biogas systems in SSA, building on experiences from other sectors. This could be linked to research into current training provisions within academic, vocational and technical institutions, with recommendations on how to develop a more industry-relevant system for developing operating and maintenance capacity.

Barrier 4: Lack of viable business models

Development of a financial modelling tool for evaluating potential biogas projects at new sites in SSA, in which multiple income streams (including electricity, heat, fertilizer and waste disposal) can be valorised to explore the commercial potential of different models. This could extend to exploring financing opportunities to bring promising opportunities closer to realisation.

Research into models of donor support for the biogas sector that ensure commitment of project developers to commercial success, with meaningful sharing of risk, and ways to maximise community or pro-poor impact.

Development of creative approaches for increasing commercial lending to biogas projects, drawing on successful financing models from other sectors, and including partnerships between development agencies and financial institutions to de-risk

lending. Cooperation with initiatives such as PFAN or the Finance Catalyst of RECP is suggested.

Barrier 5: Unfavourable policy and regulation

Financial modelling to explore the impact of different policy measures on a range of biogas configurations, considering various heat and digestate valorisation scenarios, to help guide policymakers towards realistic regulatory and tariff structures (e.g. for electricity grid feed-in) that will support growth of the industry. This could include modelling of the implications of effective enforcement of environmental regulations on the commercial case for biogas projects in SSA.

Barrier 6: Limited access to manufacturer support and spare parts

Advocacy-oriented research into the social, economic and environmental case for governments to support the development of a biogas industry in SSA countries, including co-benefits of waste disposal, fertilizer production, industrial development and job creation, to create a supportive environment for industry to invest and thus increase the access to manufacturer support and spare parts.

Summary of implications

Successive phases of BSEAA research have led to the conclusion that anaerobic digestion is the bioenergy technology which offers the greatest potential for replication in SSA at the sub-5 MW output scale, supported by evidence from successfully operating projects. Indications of potential research themes to address the identified barriers have been suggested, and the Phase II call will no doubt elicit a wider variety of ideas that DFID can screen for relevance and impact potential. DFID may also wish to focus on a sub-set of the barriers in framing its call, to maximise the impact of available resources.

The research could be undertaken by technical, academic or private sector organisations acting alone or in consortia, or even by establishing a Centre of Excellence for applied biogas research in Africa, in partnership with industry. Cooperation with other donor programmes such as the Africa-EU Renewable Energy Cooperation Programme would be valuable to maximise effectiveness and reach.

The barriers facing gasification are meanwhile too significant and wide-ranging for research to make a significant difference to uptake. Gasification-related research is therefore not deemed worth supporting in Phase II.

It is left for DFID to decide if further feasibility research into the retrofitting of sub-1 MW steam turbines for CHP to existing (agro-)industrial plants in Ghana, Kenya and Rwanda represents a useful addition to the Phase II call, balancing the inevitable dilution of resources against the benefits of exploring this lesser opportunity.

1. Introduction

A consortium of LTS International, E4tech and The University of Edinburgh is implementing Phase I of the DFID-funded Bioenergy for Sustainable Energy Access in Africa (BSEAA) research assignment. BSEAA is investigating the challenges and opportunities for the adoption of bioenergy across Sub-Saharan Africa (SSA) and supporting the development of innovative bioenergy solutions. Phase I runs for 12 months from September 2016 and aims to identify areas of potential innovation in bioenergy technology and related value chains for targeted research in Phase II. Phase II is part of DFID's larger Transforming Energy Access programme, which will test innovative technologies and business models for delivering affordable, clean energy-based services.

A six week Design Phase in 2016 resulted in finalisation of the BSEAA research methodology, results framework, work plan and research question: "*Which bioenergy technologies have the greatest potential for uptake at scale in SSA?*". It was agreed that the study would look beyond technologies in isolation and place them in the context of the 'technology value chain' (TVC), comprising a particular combination of feedstock, processing technology and end use.

Iterative phases of literature review, stakeholder mapping and TVC prioritisation from November 2016 to March 2017 led to the shortlisting of anaerobic digestion, gasification and combustion-based steam turbines as the most promising technologies for research and innovation, in ten priority countries.

18 anaerobic digestion and gasification projects in seven SSA countries were then identified and visited during May and June as case studies from which to analyse barriers and opportunities for wider replication. As no working examples of small-scale steam turbines could be found, desk research was instead conducted on the technical and economic feasibility of this technology for heat or power production at sub-1 MW scale, and areas where research could potentially make a contribution.

This Case Study Report draws upon the practical experiences of the sampled projects to identify the main barriers and opportunities for the wider adoption of anaerobic digestion and gasification in SSA, in order to identify areas of research that DFID might usefully support in BSEAA Phase II.

Phase I of the study will conclude (by September) with a Project Completion and Handover Report that will consolidate all findings and recommendations, to inform the design of Terms of Reference for the Phase II research call.

2. Approach

2.1 Objectives

This Case Study phase of the BSEAA study sought to identify barriers to the deployment and replication of bioenergy technologies in SSA, and to translate these barriers into innovation opportunities that DFID-supported research could potentially address in Phase II. The analysis was based on a series of visits by study team members to operational examples of anaerobic digestion and gasification TVCs across the region.

A lesser objective (agreed with DFID after the previous deliverable) was to conduct a targeted piece of techno-economic research into the viability of combustion-based steam turbine technology at the sub-1 MW scale, given the absence of installations of this size and the questions this raised on potential research and innovation opportunities.

2.2 Case Study identification

Much groundwork had already been undertaken in preparation for the Case Study phase during the earlier Literature Review, Stakeholder Mapping and TVC Prioritisation stages (November 2016 to March 2017). An exhaustive list of 27 bioenergy technologies had been reduced to 15 and eventually to three, while a database of 257 resource persons was refined to a shortlist of 70 with the most relevant technical or institutional knowledge, who were contacted directly for project and sector information. Combined with systematic online research covering 28 SSA countries, the result was a comprehensive database of 153 TVC examples in various stages of development across Africa representing the three shortlisted technology options. These shortlisting and prioritisation processes are fully described in the earlier reports submitted to DFID.

A sample of Case Studies for analysis was then chosen from the project database according to the following criteria:

- Incorporating either anaerobic digestion or gasification technology;
- Producing heat and/or power in the 10 kW_e to 5 MW_e output range;
- Located in one of the ten BSEAA priority countries[1], though retaining flexibility to capture interesting case studies located elsewhere;

[1] Ethiopia, Kenya, Tanzania, Uganda, Rwanda, Ghana, Nigeria, Mozambique, Zambia and South Africa.

- Believed to be currently operational or recently so;
- Having an identifiable project operator prepared to host visitors and share information; and
- Being accessible within reasonable limits of time and finance.

An intensive period of research during April and May revealed that only around 20 of the 153 identified project examples met these criteria. From among the priority countries, no qualifying sites were found in Ethiopia, Mozambique or Rwanda, and only a single biogas plant producing power was found in Zambia and it was not deemed cost-effective to organise a one-site country mission. Two regional case study tours were designed to the other six countries, the first to east and southern Africa (from 8th to 25th May) and the second to West Africa (from 19th to 29th June). Senegal was included in the second mission to capture two particularly interesting case studies, despite not being a BSEAA priority country. A short trip was also made to Munich in early July to meet biogas industry representatives under the auspices of the German Biogas Association and to the World Biogas Expo in Birmingham to discuss barriers and opportunities with technology providers and project developers involved in anaerobic digestion projects in Africa. The full itineraries of these missions, detailing the locations visited and people met, are in Annex A.

A total of 18 Case Study sites were visited in seven countries by the Team Leader (representing LTS International) and the Technical Advisor (from E4tech)[2].

Basic details and locations are provided in the tables and maps below. The 12 anaerobic digestion projects are coded AD1 to AD12 and the six gasification projects are coded G1 to G6.

Technology providers are indicated for the gasification projects but not for the biogas projects as they involve so many different suppliers. Note that the rated power output of each installation (in kW_e) is indicative of the intended capacity and may not reflect actual operating output, or indeed whether power is being produced at all.

[2] Matthew Owen and Ralph Ripken. Ankit Agarwal (LTS) also joined in Kenya from 10th to 12th May.

Table 1. Anaerobic Digestion Case Study summary

Code	Country	Location	Developer	Feedstock(s)	Rated output (kW_e)
AD1	Senegal	Dakar	Société de gestion des abattoirs du Sénégal	Abattoir waste	100
AD2	Ghana	Adeiso, Eastern Region	HPW Fresh & Dry	Fruit waste	96
AD3	Ghana	Ashaiman, Greater Accra	Safi Sana International	Waste from market, toilets & abattoir	100
AD4	Nigeria	Papalanto, Ogun State	Avenam Links International	Poultry manure	5.5
AD5	Uganda	Kampala	Makerere University & City Abattoir	Abattoir waste	30
AD6	Kenya	Saosa, Kericho	James Finlay Kenya	Spent tea	160
AD7	Kenya	Gorge Farm, Naivasha	Tropical Power	Crop waste	2,300
AD8	Kenya	Kwa Samaki, Murang'a County	Olivado	Avocado skins & stones	445
AD9	Kenya	Kilifi, Coast Province	Kilifi Plantations	Sisal waste, mango waste, cattle manure	150
AD10	Tanzania	Hale, Tanga Region	Katani	Sisal waste	300
AD11	South Africa	Mandini, KwaZulu-Natal	Sucropower	Napier grass	18
AD12	South Africa	Pietermaritzburg, KwaZulu-Natal	Renen	Horticulture waste	50

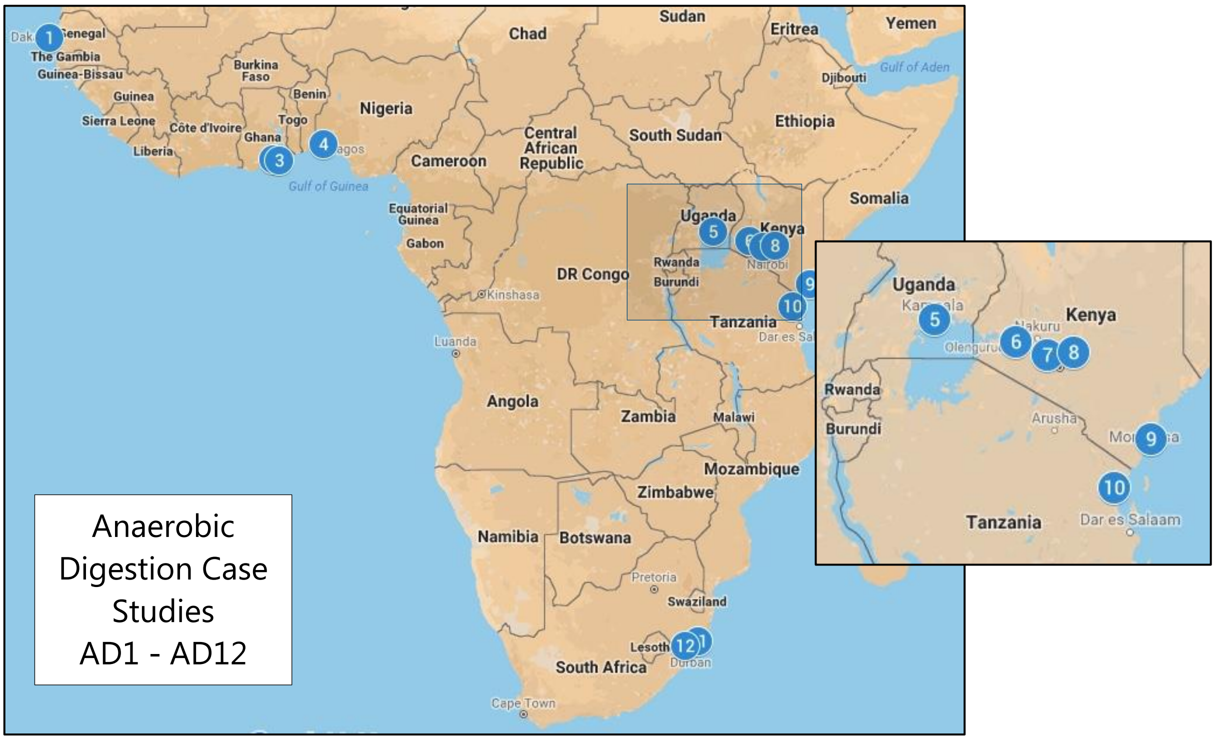
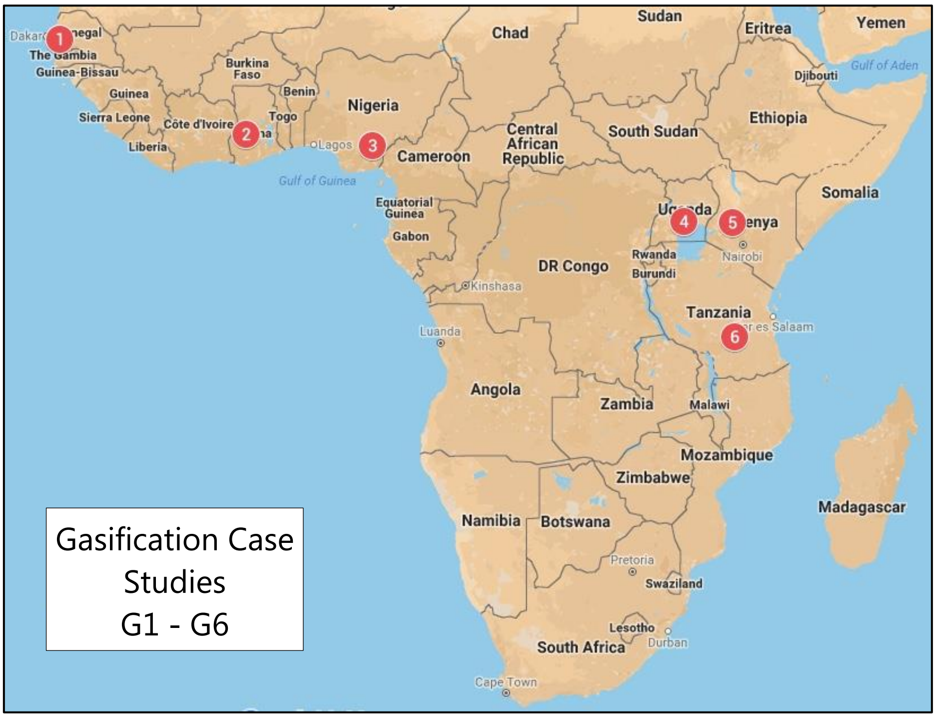


Table 2. Gasification Case Study summary

Code	Country	Location	Developer	Technology provider	Feedstock(s)	Rated output (kW_e)
G1	Senegal	Kalom, Diourbrel Region	Novis GmbH	Ankur Scientific, India	Peanut shells	25.6
G2	Ghana	Papasi, Ofinso North District	Kumasi Institute of Tropical Ag.	All Power Labs, USA	Palm kernel shell	24.8
G3	Nigeria	Ngbo, Ebonyi State	Ebonyi State Government	IISc, India	Wood wastes	32
G4	Uganda	Ssekanyoni, Mityana District	Pamoja Cleantech	Husk Power Systems, India	Maize cobs	32
G5	Kenya	Marigat, Baringo County	Cummins Cogeneration	Biogen, Dominican Republic	Wood chips	2,400
G6	Tanzania	Mngeta, Morogoro Region	Kilombero Plantations	Fengyu Group, China	Rice husk	500



The country visits gave a convenient opportunity to meet locally-based experts to gather contextual information and supporting opinions. These parallel discussions are summarised in Annex B (Country Scoping Reports)[3] and were a helpful addition

[3] The title 'Country Scoping Reports' reflects a separate deliverable that was originally foreseen, and later merged with this Case Study Report with DFID's approval.

to the Case Study visits for enhancing the analysis of barriers and opportunities for replication. Whilst in Ghana, study team members also attended the fifth ECOWAS/GBEP Bioenergy Week in Accra from 22nd to 24th June and were able to share knowledge and experiences on sustainable bioenergy service delivery with representatives of the ECOWAS member states, FAO, GIZ and the private sector.

2.3 Case Study format

A standard set of questions was developed for the two categories of Case Study and was used as a checklist during the site visits. It did not always prove possible to gather a full set of technical data, especially for projects still being commissioned.

At each location, the underlying aim was to identify the barriers to replication of a particular bioenergy technology that DFID-supported research could potentially help unlock. The Case Studies themselves are posted individually in Annex C (anaerobic digestion) and Annex D (gasification). Draft versions were checked for factual accuracy by the respective project developers[4]. The opinions they contain are nevertheless those of the DFID-contracted consultants, and may not always reflect the developers' own views. The analysis in the main report draws together the barriers and opportunities from all of these Case Studies.

2.4 Steam turbine research

The free-standing piece of techno-economic research into the potential for combustion-based steam turbine technology at sub-1 MW scale was carried out by technical staff of LTS, with the support of The University of Edinburgh Faculty of Engineering and experts at E4tech. This self-contained piece of work, conducted in parallel to the Case Study analysis, had been proposed during the previous phase (and endorsed by DFID) when it became clear that there were no identifiable biomass-powered steam turbine projects in SSA in the sub-1 MW output range. While numerous larger installations can be found, especially in sugar mills, the apparent absence of smaller units was thought worth investigating to identify any potential research and innovation opportunities. This steam turbine research has been placed in Annex E and a summary of the findings and implications is included in section 3.4 of the main report.

[4] In three cases (AD3, AD10 & G4) the project developer did not revert with any corrections, so those particular reports are not 'fact-checked'. This is indicated at the end of the respective Case Study.

3. Barriers to Replication

3.1 Introduction

The 18 Case Study reports in Annex C and Annex D provide a wealth of operational detail on the prominent examples of anaerobic digestion and gasification that were visited in SSA. This chapter draws out the challenges encountered by the operators of these projects, supplemented by the additional consultations held with project developers, technology providers, financing institutions and sector experts.

The analysis of barriers is intended to guide the direction of BSEAA Phase II by ensuring that the research supported by DFID responds in the most relevant way to the specific challenges being faced by developers on the ground.

Anaerobic digestion is addressed first and gasification second. The findings of the steam turbine research are summarised at the end of the chapter.

3.2 Anaerobic Digestion

3.2.1 Introduction

Despite anaerobic digestion being a TRL9 technology that is well developed in industrialised countries, there are fewer than 20 functioning commercial biogas systems producing heat and power in the whole of SSA, and this small sample is dominated by South Africa and Kenya.

The barriers and challenges experienced by the developers of the 12 anaerobic digestion projects visited can be classified into six categories relating to feedstock supply, technology, operational capacity, business models, policy and regulation, and manufacturer support and spare parts.

3.2.2 Barriers

Barrier 1: Unreliable feedstock supply

Access to a reliable source of feedstock of consistent quality and price is clearly a pre-requisite for a viable anaerobic digestion plant. In each of the successful projects visited, the primary feedstock is available on site as a by-product of the developer's own core business or that of an adjacent business with an equity stake. The fruit processor HPW in Ghana, for example, uses mango and pineapple residues from its own operations (AD2); James Finlay Kenya uses spent tea from its soluble tea factory (AD6); Olivado Kenya uses avocado skins and stones from its edible oil processing plant (AD8); Kilifi Plantations uses sisal waste and cattle slurry from its own estate (AD9); and Katani in Tanzania uses waste from its adjacent sisal decorticator (AD10).

Shortage of feedstock and high costs of procurement are meanwhile a significant constraint for Safi Sana in Ghana (AD3), which is obliged to truck in three types of raw material from market traders, an abattoir and communal toilet blocks scattered across the local municipality, contributing to an 80% shortfall in expected gas output (and income from electricity sales). Another plant intending to bring feedstock from off-site is being set up in South Africa by Sucropower (AD11). While the plant was not yet commissioned during the visit, the unproven economic case for farmers to plant Napier grass to supply the biogas plant instead of growing sugarcane, the established local cash crop, casts doubt on the viability of the out-grower model.

In fact no successful example could be found where the primary feedstock was being brought in from elsewhere (although at Kilifi Plantations in Kenya [AD9], supplementary mango residue from an off-site fruit processor is added to the company's own wastes and poultry manure is added at HPW's biogas plant [AD2] in Ghana). Projects relying on remote feedstock supply may become dependent on third parties for setting the price of their raw materials and ensuring adequate supply. This risk has been addressed by Tropical Power by ensuring that VegPro Group, which generates its feedstock, has a 50% stake in the biogas business so is incentivised to keep it supplied with raw material and running profitably - especially as the digestate reportedly contributes to an 8-10% saving in VegPro's total running costs by replacing synthetic fertilizer in its horticulture operations.

Ensuring a reliable supply of feedstock is also a matter of exploring all locally available options. Tropical Power is located in Kenya's main flower-growing region and has been investigating the breakdown of lignin-bound rose waste as a potential supplementary feedstock to compensate for a shortage of vegetable residues from VegPro (provided that the pesticides used on the roses do not adversely affect the biological conditions in the digester). Technologies for preparing lignocellulosic wastes have been successfully tested in Europe by companies such as Biobang (Italy), and the first systems are being built in the UK by Cavimax and Future Biogas.

Other work by Tropical Power has highlighted the gas-producing potential of crassulacean acid metabolism[5] (CAM) plants, which are highly water-efficient and can be grown in drought-prone regions. CAM plants may represent a real breakthrough in expanding the range of feedstocks for biogas systems in SSA.

Research into novel feedstocks, particularly those unique to Africa, could potentially increase the uptake of anaerobic digestion beyond the range of materials currently being used, and also improve conditions inside digesters and increase productivity.

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[5] en.wikipedia.org/wiki/Crassulacean_acid_metabolism

Barrier 2: Costly and insufficiently adapted technology

The leading developers of industrial-scale anaerobic digestion systems are found in Europe and North America, where labour is expensive so a high degree of automation is desirable. These systems tend to be built to a high specification using premium materials and durable components. Income projections are frequently based on predictable revenue flows from government-subsidised power purchase agreements (e.g. feed-in-tariffs in Germany). High capital expenditure is not necessarily a barrier under these circumstances, because system sophistication minimises operation and maintenance costs, while market conditions ensure that income flow is reliable and payback is predictable, despite the high up-front cost.

A rather different situation prevails in Africa, where labour is generally cheaper, high quality construction materials and system components are more difficult to source, and there are usually no renewable energy subsidies[6]. High capital costs can be a significant barrier to investment under such circumstances, implying a need to reduce the costs of biogas systems to promote wider adoption. This necessitates trade-offs between full automation and partly manual systems of operation, and between the best build quality and cheaper but potentially less durable alternatives.

Table 3 summarises the capital cost of those Case Study installations for which data was available, expressed in USD per unit of installed power and/or heat output.

Table 3. Capital expenditure of biogas plants per rated output of heat or power

Code	Developer	Country	Capex per kW_e (USD)	Capex per kW_{th} (USD)
AD1	SOGAS	Senegal	9,900	6,600
AD2	HPW Fresh & Dry	Ghana	4,700	1,100
AD3	Safi Sana International	Ghana	20,800	20,800
AD4	Avenam Links	Nigeria	6,700	-
AD5	Makerere Univ. & City Abattoir	Uganda	n/a	-
AD6	James Finlay	Kenya	12,500	11,800
AD7	Tropical Power	Kenya	3,000	n/a
AD8	Olivado	Kenya	2,200	1,700
AD9	Kilifi Plantations	Kenya	4,000	n/a
AD10	Katani	Tanzania	5,000	-
AD11	Sucropower	South Africa	17,100	9,600
AD12	Renen	South Africa	5,700	2,600

[6] A tariff of US 0.175/kWh paid to Safi Sana in Ghana (AD3) represents an exception.

There is enormous variation in unit cost, indicative perhaps of the diversity of technological solutions being applied, the wide range of outputs scales (and related economies) and a young and unsettled technology market.

Olivado in Kenya (AD8) so far promises to deliver the most economical system for both power and heat production, but its plant is still under construction and costs may rise. The most expensive installation is that of Safi Sana (AD3), a donor-funded plant in Ghana, followed by Sucropower in South Africa, which is a small 18 kW_e system that doesn't benefit from economies of scale (and with 55% donor funds could potentially be over-priced). The James Finlay plant in Kenya is the most expensive of the privately financed installations, but at the same time benefits from sophisticated German technology and is operating at a high level of performance and reliability, with proven commercial success.

A number of local developers are trying to achieve a viable balance between cost and performance for the SSA context. Avenam Links International (AD3), for example, works with private clients in Nigeria to develop affordable biogas systems that use low-cost components, and has recently installed a basic biogas-to-power plant at a poultry farm in Ogun State for under USD 40,000 (USD 6,700/kW_e) using Chinese 'red mud' digester and gas bags. Thecogas's abattoir plant in Senegal (AD1) uses a lagoon digester that does not require an expensive concrete basin. Capital costs per unit of output are still high, however, at USD 9,900/kW_e installed. Biogas technology providers such as Wiefferink (Netherlands) offer lagoon digester systems with the specific aim of reducing capital costs. Makerere University (AD4) has built a demonstration biogas plant at an abattoir in the Ugandan capital from materials sourced locally, with the exception of an Italian air blower. Renen in South Africa (AD12) has adapted Induced Blanket Reactor technology from the USA by replacing expensive cylindrical digesters with standard shipping containers that are widely available in Africa. Sucropower, also in South Arica (AD11), has employed a local technology provider to install modular steel digesters that can be bolted together in a matter of days, connected to a low-cost Chinese gas engine.

The most interesting approach may prove to be that of Olivado in Kenya (AD8), which aims to retain high German design principles, but to use local contractors and to source cheaper components from outside Europe where feasible. Its submerged digester tanks have been hand-dug and lined with plastic sheeting, rather than cast concrete, components have been procured from economical Indian and Israeli suppliers, and second-hand gas engines are being sourced. As Table 3 shows, the net result may be a very significant cost saving compared with similarly sized plants using only European technology.

Apart from Makerere University's small demonstration plant at the Kampala City abattoir (AD5), however, none of these cost-saving concepts have been proven as

the plants in question are either still being commissioned, have been operating for only a few months or have not been operationally reliable. Early observation suggests that certain crucial components such as mixers and pumps need to be of premium quality, even if cost-savings are made elsewhere, as they require precisely engineered bearings to ensure long-term reliability and operation.

Adaptation of technology for Africa is not only a matter of cost-saving, but also one of customisation for specific local operating conditions. The operating environment in SSA tends to be harsher than in industrialised countries, where more consistent standards of construction, operating protocols and maintenance regimes are likely to be applied. Larger design tolerances are required in SSA to allow for non-standard operating practices, weaker technical capacity and less stringent plant management. The Case Study examples reveal shortcomings where designs have been transferred without modification to SSA and proved inappropriate for conditions on the ground.

At Katani in Tanzania (AD10), long sisal fibres are not being adequately eliminated from the incoming waste stream because inoperative chopping equipment at the decortication plant has been bypassed, resulting in clogging of mixers and pumps in both the pre-mixing and hydrolysis tanks. This has in turn led to breakage of those pumps and mixers, and to scum formation and suppressed gas yields in the digester. Tropical Power in Kenya (AD7) found that feeding maize stems directly to a German-built digester designed to handle ensiled maize resulted in formation of a spongy surface layer of plant matter because the local, non-ensiled feedstock retained a waxy eternal coating which caused it to float. The operator was obliged to retrofit an upgraded vertical mixing system to address the problem.

The James Finlay Kenya plant (AD6) neatly avoids the clogging problem because the substrate is mixed and heated *outside* the main digester tank, allowing full access to the equipment in the event of any problems without needing to open up the digester itself. This may be a special case, however, as tea waste is well suited for spray nozzles that distribute the substrate in the digester, which would become clogged by more fibrous feedstocks. The biogas technology design needs to account for such feedstock differences and the impact they might have on the effectiveness of mixers (at HPW [AD2] & Tropical Power [AD7]) and clogging of substrate pipes (at HPW) or the effects of strong sunlight on gas storage bags (also at HPW).

In the equatorial regions of SSA, feedstock is available year-round and demand for digestate may likewise be continuous, in contrast with Europe where the supply of inputs and the demand for some outputs (especially fertilizer) tend to follow a distinct seasonal pattern. Cheaper digesters can potentially be built for SSA with smaller tanks for pre-mixing and digestate storage. In southern Africa, with its more pronounced seasonal weather pattern, feedstock supply may sometimes dry up completely and equipment needs to be sized and configured differently.

State-of-the art, mainly European technologies certainly have their place in well-resourced agribusinesses such as James Finlay Kenya (AD5) and Tropical Power (AD6), with sufficient internal capacity to operate complex automated systems. It will clearly be necessary, however, to develop systems that are both cheaper and are adapted to African climate, seasonality, feedstocks, technical capacities and operating realities, if the next tier of potential adopters is to find anaerobic digestion an attractive and affordable technology choice.

Barrier 3: Limited operator technical capacity

Anaerobic digesters operate according to known scientific principles and basic parameters such as temperature, pH, solids content and microbiological conditions need to be optimised or systems will under-perform or even cease to function. The apparently passive nature of biogas production belies the significant technical knowledge and practical experience that must be vested in operators.

Several project developers (including HPW and Safi Sana in Ghana [AD2 & AD3], James Finlay and Tropical Power in Kenya [AD6 & AD7] and Katani in Tanzania [AD10]) have their own lab facilities for monitoring digester temperature, pH and nutrient composition, as well as H_2S, CH_4, CO_2 and moisture content of the biogas. HPW (AD2) systematically monitors the biogas twice each day to pick up any changes in characteristics. Protocols are also in place at some plants for monitoring other important parameters such as organic acids, trace elements and ammonia, to understand the health of the digestion process. Three of the higher-spec systems (James Finlay, Tropical Power and Kilifi Plantations in Kenya [AD6, AD7 & AD9]) permit real-time monitoring of operational parameters via live data connections and are linked to the equipment manufacturers in Germany, from where malfunctions can be identified and communicated to the site operators. It is no coincidence that these projects with a direct technical support line to the manufacturers are also the only truly successful projects in the sample.

It is of course vital that the substrate is well managed to sustain a balanced digestion process that maximises gas output. Poor management may be manifested by scum formation, blockage of pumps and mixers, flaccid gas storage bags, poor performance of connected engines or even acidification of digesters.

At the *Société de gestion des abattoirs du Sénégal* (SOGAS) abattoir in Dakar (AD1) an excess of ammonium-rich blood compared with solid feedstock from cattle stomach contents has led to an imbalance in the digestate C:N ratio that has negatively affected gas output. At the HPW plant in Ghana (AD2), a sudden change in substrate composition due to a seasonal excess of acidic pineapple waste probably contributed to such a significant drop in pH that one of the two digesters had to be shut down and emptied. Bringing in supplementary feedstocks may be necessary to ensure a

viable chemical balance in such cases, but the costs of doing so represent a barrier for sustainable operation. The experience also demonstrates the importance of well-trained operators with relevant practical experience.

Safi Sana in Ghana (AD3) is blending three feedstocks with very different characteristics from a market, an abattoir and public latrines. Poor feedstock preparation or substrate management is evidenced by a thick surface scum in the digester, a digester temperature 10% below target levels, a requirement for post-digester mesophyllic composting due to the presence of faecal matter in the substrate, and a connected gas engine operating 80% below design specification. The Katani operation in Tanzania (AD10) shows similar tendencies, with thick scum build-up in the digester, breakage of pumps and mixers, and engine under-performance, most likely resulting from excessive long fibre content in the sisal waste feedstock.

Plant managers with specific technical training in anaerobic digestion were found at Thecogas Senegal (AD1), James Finlay Kenya (AD6), Olivado (AD7), Kilifi Plantations (AD9) and Renen in South Africa (AD12). At HPW in Ghana (AD2), a technician with a renewable energy background was re-trained on site in the operation of the biogas plant. At Katani in Tanzania (AD10) staff had also received on-site training from the technology provider (BioEnergy Berlin), four staff went on a study tour to China and one was sent to the Netherlands. At James Finlay Kenya (AD6) the operator was sent for a three month training period to Germany visiting various plants and working alongside engineers from the different equipment suppliers.

There are currently no standardised technical or practical training facilities on the continent where the necessary skills and competencies to operate a modern commercial biogas plant can be acquired. The focus is on small-scale digesters for household use in the context of rural development programmes. This acts as a barrier to other agribusinesses potentially investing in biogas systems, which can be rightly perceived as complex and hard to manage.

There is a need to elevate skill levels within the African biogas sector through technical training courses, apprenticeships and university modules focused on the practicalities of biogas plant operation, as well as hands-on operational experience. Higher indigenous skill levels will in turn have positive feedbacks for the development of local biogas support structures and technical back-up, as more skilled workers become available and attract more technology providers to invest.

Barrier 4: Lack of viable business models

Insufficient valorisation of outputs

In the European context it is possible to run a commercially viable anaerobic digestion plant on the basis of electricity sales alone, thanks to subsidies linked to

national emissions reductions targets. The Case Studies suggest that biogas developers in SSA will usually need to valorise multiple outputs in order to deliver a competitive business proposition[7].

At the James Finlay plant in Kenya (AD6), for example, the gas engine produces power and heat for the tea factory, while the digestate is used to fertilize organic tea. At Tropical Power in Naivasha (AD7), both power and digestate are sold to the neighbouring farm while a power purchase agreement is in place to sell excess power to the national grid, and hot water will shortly be sold to another farm to heat flower houses. Renen in South Africa (AD12) expects to generate electricity, provide root zone heating to a farm nursery; supply pre-heated water to an essential oil processing facility and market enriched organic fertilizer.

Some projects valorise only one of the outputs, such as the biogas plant at Katani in Tanzania (AD10) where there is no value placed on avoided waste disposal, heat output or fertilizer. The economic viability of this model is questionable as a result.

Reliance on a sole income stream will rarely be a viable biogas strategy in SSA, and systems to valorise multiple outputs need to be researched and developed. This requires careful site selection and pre-planning to ideally guarantee avoided costs of waste disposal together with on-site applications for electricity, heat and fertilizer - before the plant is actually built.

Lack of operator investment

Commercial viability also depends on the motivation of the project operator. Evidence from the Case Studies suggests that successful operation depends strongly on the degree to which project owners have financially invested in the enterprise. James Finlay (AD6), Tropical Power (AD7), Kilifi Plantations (AD9) and HPW (AD2) are privately-funded initiatives that deliver direct commercial benefit for the associated tea, horticulture, fruit and sisal operations, through valorisation of fertilizer plus electricity and/or heat[8]. The first three (and HPW to a lesser extent) have been operating successfully and apparently profitably for several years. Olivado in Kenya (AD8) and Avenam Links in Nigeria (AD4) similarly represent private investments with clear expectations of financial benefits to the project owner, though are too new to draw firm conclusions on viability.

In each of these cases, not only has funding come from private sources, it is also notable that the owner of the site and the feedstock, the operator of the project and

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[7] With the possible exception of Ghana, where the national utility offers an attractive feed-in tariff for biogas-generated power of US 0.175/kWh. Safi Sana's plant in Accra (AD3) can in theory generate just over USD 10,000 per month from electricity sales alone.

[8] The Kilifi Plantations plant (AD9) did receive co-finance from GIZ but the owner contributed 50%.

the beneficiary of the outputs are essentially the same entity (albeit with internal equity overlaps at Tropical Power and Kilifi). In other words there is a set of common interests and a vested corporate incentive to succeed.

In contrast, projects that have been 100% grant funded have encountered significant viability problems. They are far more likely to lack a realistic business model and a serious commercial outlook to the way they operate, with the result that running costs are frequently too high in comparison with income and sustainability is placed in jeopardy. While it would be unfair to flag particular projects as the study team were not invited in as evaluators, site visits suggest that installations with full grant funding have a greater tendency to acquire large offices and vehicles, seem to have more staff than are necessary for efficient operation, and are failing to capture sufficient revenue to cover maintenance costs - with the result that their systems are becoming progressively more dysfunctional.

Lack of commercial financing

The tendency for project developers to seek grant funding may in part reflect lack of access to commercial finance for anaerobic digestion projects. Developers report that it is challenging to secure loans for biogas plants in SSA, meaning that investments must be self-funded by the project developers or their clients. Small project sizes (<USD 5 M) are ironically often more difficult to finance than larger ones (>USD 20 M). An impression of the apparent complexity of biogas projects in the investment community does not help. Even loans provided by European government sources on attractive terms sometimes become unattractive as local African banks add a risk premium, making the final interest rate non-viable. This may be preventing many potential projects from going ahead, leading developers to suspend their plans or seek alternative assistance in the form of grants. Grant funding is certainly not a panacea and may in fact undermine rational commercial practice, as explained.

This has implications for the way donors apply their funds. More strategic options such as results-based financing mechanisms, shared investment or de-risking of commercial financing during a long development period of up to five years may be more helpful than 100% grants.

Lack of project pipeline

Linked to the financing challenge is an absence of investible biogas projects in SSA. While a number of one-off country studies have investigated the potential for new biogas developments from a technical perspective, there are few systematic efforts to identify a portfolio of opportunities that can be advanced to commercial bankability by creating the necessary linkages between technology providers, project developers and financiers.

The Africa-EU Renewable Energy Cooperation Programme (RECP), the Renewable Energy Performance Platform (REPP) and the Private Financing Advisory Network (PFAN) are addressing this challenge to some extent. RECP runs a project with three components that covers project scouting, access to finance and policy advisory services, but is currently only considering bioenergy opportunities in Uganda. PFAN offers mentoring on business plan, growth strategy and matches projects with potential investors. REPP provides technical assistance to reach financial close and provides access to long-term lending as well as results-based financial support. There is potential to collaborate with such scoping and match-making programmes to expand their reach and effectiveness.

Barrier 5: Unfavourable policy and regulation

Lack of incentives to move beyond captive demand

The early developers of biogas projects in SSA are mostly targeting captive demand for heat and power within large agri-businesses, to help them offset consumption of grid electricity or fossil fuel. Kilifi Plantations in Kenya (AD9), for example, sells power to its sister company operating the adjacent sisal and cattle estate at 15.5 US cents/kWh, a saving against the utility tariff of US 18 cents/kWh. Tropical Power (AD7) reports a similar situation, selling its power to VegPro with grid sales only a last resort for any surplus at just 10 US cents/kWh. Katani in Tanzania (AD10) sells electricity to the adjacent sisal processing plant at 15.7 US cents/kWh, a rate reportedly far more attractive than the feed-in tariff offered by the utility. HPW in Ghana (AD2) produces heat for its own fruit drying operations, offsetting demand for diesel to fuel its boilers.

While these appear to be viable tariffs for the African context, project developers need incentives to move beyond the captive demand model if the full potential of biogas in SSA is to be realised. Grid feed-in is one option but only two of the 12 profiled projects have a Power Purchase Agreement in place, the first being Safi Sana (AD3) in the unique setting of Ghana with its exceptionally high feed-in tariff (USD 0.175/kWh), and the other being Tropical Power in Kenya (AD7), where grid sales are a last resort for any surplus power. Across most of SSA, feed-in tariffs for biogas-generated power either do not exist in law or have been set at levels which are economically marginal. In South Africa they are reportedly lowest of all due to the price-deflating effect of coal-generated power.

The number of opportunities to exploit captive power demand are finite, once the larger agribusinesses have adopted biogas technology. Future projects will be looking increasingly to external revenue streams and the most obvious is power supply to the grid. This can only happen if feed-in tariffs are more attractive and consistent. Anaerobic digestion has the potential to improve grid reliability and

energy access, so represents an additional source of power that national utilities should find attractive.

Tariff-setting is a matter for policymakers at country level. Their decisions can favour or disfavour the large-scale deployment of biogas, because an attractive feed-in tariff can contribute to a predictable income for a plant, besides the valorisation of heat and digestate, and convince investors to go ahead with a project that might otherwise be marginal.

A research programme such as BSEAA could potentially advance this agenda by investigating which policy mechanisms would best support the development of anaerobic digestion in Africa beyond sites of captive demand.

Non-enforcement of environmental regulations

Biogas plants offer an effective means of cleaning up polluting waste streams that would otherwise be discharged into surface drains or landfills. If governments enforce environmental regulations with punitive fines, then a significant cost saving may be achieved by using a biogas plant to convert pollutants into sanitised digestate that has value in its own right and can produce heat and/or power in the process. Avoided disposal costs can then represent a significant element in the investment decision. In many SSA countries, however, environmental regulations are not consistently enforced and polluters may face no penalties for indiscriminate dumping of waste. This denies developers the benefit of cost-saving associated with a biogas plant.

At the Kampala City Abattoir (AD5), for example, 400,000 l per day of liquid waste are ejected into an open drain with no control at all by the Kampala Capital City Authority. This renders any attempt to clean up this waste a demonstration of good practice rather than a cost-saving for the abattoir management. The situation at the SOGAS abattoir in Dakar (AD1) is similar, where the liquid waste stream is directly released into the sea as a potential fine is not applied. At the Katani sisal factory in Tanania (AD10), effluent is ejected directly into the Pangani River without any financial consequences. The poultry farm in Nigeria where Avenam Links has recently installed a biodigester (AD3) has been dumping untreated manure and other waste from 13,000 layers into an open lagoon, with resultant pollution of the farm's own groundwater supply. There is no enforcement of environmental regulations and therefore no cost-saving for the farmer from putting this waste through a biogas digester. The benefits in this case will come from power generation and fertilizer sales (though hopefully the farm's water supply will also become cleaner).

Larger agri-businesses are more likely to be targets for environmental enforcement agencies and may thus have most to gain from proper waste disposal. This is certainly the case for James Finlay Kenya (AD6), which takes corporate responsibility

seriously for good waste handling practice and comes under public scrutiny. Similarly at HPW in Ghana (AD2), which has to pay for its fruit waste to be taken away and composted. Olivado (AD7) only received a temporary environmental permit to store avocado waste on-site, pending construction of a biogas plant to treat the waste stream.

Smaller businesses in the informal sector are more likely to get away with illegal dumping practices and are thus less likely to benefit financially from improving their management of waste. It is these smaller, lower profile businesses which then lack the avoided disposal costs that a biogas plant would deliver. This acts as a further barrier to adoption of the technology outside the large, well-resourced agri-businesses where it is currently concentrated.

Barrier 6: Limited access to manufacturer support and spare parts

Only one non-African biogas technology provider is known to have established a permanent presence in SSA, with the 2014 arrival in Cape Town of Anaergia (which took over German UTS Biogastechnik in 2007). Others such as AKUT in Kenya or PlanET in Ghana have consultants acting as local agents or advisors. The strategic development priority for European biogas developers and technology providers lies in Asia and Latin America, where there are larger agricultural and industrial concentrations, and more favourable investment conditions. Pursuing biogas opportunities in Africa appears not to be a strategic exercise, but takes place on an opportunistic basis, invariably via personal connections.

Most project managers of biogas plants on the continent must therefore be fully self-contained with their own in-house personnel, as they cannot rely on technical staff flying in from an off-shore supplier once an initial warranty period is over. It was reported by James Finlay Kenya (AD6) that AKUT had provided this service, and Thecogas Senegal (AD1) has a service agreement with Thecogas NL who reportedly send an engineer twice a year. The durability of these arrangements beyond the first year or two after commissioning is unproven.

The same limitation applies to spare parts as it can take many weeks to procure standard components due to inefficient and potentially corrupt import procedures. Several countries have exemptions from import duties for equipment needed to set up new plants, but subsequently impose taxes on replacement parts. HPW in Ghana (AD2) waited six months for a replacement stirrer to be shipped from Europe, impacting its pre-mixing process in the meantime and perhaps contributing to its tank acidification problem. James Finlay Kenya (AD6) waited three weeks for a replacement alternator, a service that would take 24 hours within Europe.

Africa represents a relatively small opportunity for international technology providers and the incentive to invest in a permanent presence on the continent has so far been

limited. But at the same time, no single provider is believed to have more than three installations so far outside South Africa and it may require one company to establish a permanent presence if they are to take a dominant position and achieve a critical mass of projects. Establishing a local office with service engineers, a stock of spare parts and the ability to provide operation and maintenance contracts could help to catalyse further biogas project uptake once the first critical mass of projects exists, or might help to build this critical mass of projects and could be introduced along with long-term skills development programmes.

Encouraging technology providers to enter the African market to overcome the 'chicken and egg' problem may require external (e.g. donor) support to reduce risks and share costs, until a viable pipeline of projects can be built up.

3.2.3 Summary

There are a number of significant barriers to the adoption and replication of anaerobic digestion at scale in SSA. Only three of the 12 projects profiled can be deemed fully technically and commercially successful, in that they have a demonstrable record of reliable operation, routine maintenance and sustained delivery of valorised outputs over a period of several years. On the positive side, this shows that biogas projects can be successfully developed and operated in SSA under the right conditions. These successful installations seem to share the following characteristics:

1. Sufficient **feedstock is available on-site** under the developer's or project owner's direct control;
2. The **feedstock provider has a vested interest** in project success, either being the same company or an equity partner;
3. **Multiple outputs are valorised**, typically electricity plus fertilizer, and sometimes also heat and avoided waste disposal costs;
4. There is an **overt commercial orientation**, with no or limited grant funding; and
5. The developer has **strong technical competence** in managing anaerobic digestion plants.

Ensuring these pre-conditions for successful operation requires the variety of identified barriers to be overcome, and in those areas where research and innovation has a role to play, BSEAA may be able to make a useful contribution. Suggestions for Phase II research opportunities are provided in section 4.

3.3 Gasification

3.3.1 Introduction

Four of the gasification Case Studies are community-based installations designed to provide electricity to rural mini-grids (projects G1 to G4 in Senegal, Ghana, Nigeria and Uganda). The Cummins project in Kenya (G5) is meanwhile intended to supply power to the national grid, while the plant at Kilombero Plantations in Tanzania (G6) was set up to provide electricity to a self-contained agricultural consumer.

Gasification was chosen in each case as a relatively low-cost technology option for producing electricity available at small-scale below $100kW_e$ (e.g. in comparison with small-scale steam turbines). As revealed by the site visits, however, the barriers experienced by the developers of these projects may be similar in nature to those facing anaerobic digestion, but tend to be more significant and harder to surmount, making replication potentially very challenging. This confirms earlier assessments by GIZ and the World Bank Biomass Gasification Monitoring Programme from the 1980s and 1990s[9].

3.3.2 Barriers

The gasification barriers can be classified into five categories that relate to feedstock specifications, technological limitations, commercial viability, technical capacity and manufacturer support.

Barrier 1: Feedstock quality and availability constraints

Gasification projects face a challenge in securing consistent quantities of feedstock at low cost that meet the quality specifications of the reactor system. Quantity, quality and cost are closely interlinked, as gasifiers are intolerant of wide quality variation and this limits the range of potential feedstocks that a particular unit might be able to use. This in turn makes it even more important to guarantee the price and supply security of the preferred feedstock than it might be for other bioenergy technologies.

Gasifiers are sensitive to feedstock moisture content, heating value and particle size, and usually require clean, homogenous material that is low in ash with a moisture content of 13% or less. Dried wood chips or pellets are used in most small-scale gasifiers in Germany and the UK, but the projects visited in SSA use a variety of less uniform agricultural agri-processing by-products such as peanut shells (G1: Novis in

[9] **GIZ (2012)** *Small-scale Electricity Generation from Biomass. Part I: Biomass Gasification.* Eschborn; **Strassen, H.E.M. (2012)** *Field monitoring results in developing countries,* pp 359-373 in: *Handbook of Biomass Gasification* by BTG Netherlands, ed. Harrie Knoef. Enschede.

Senegal), palm kernel shells (G2: KITA in Ghana), maize cobs (G4: Pamoja Cleantech in Uganda) and rice husk (G6: Kilombero Plantations in Tanzania).

KITA in Ghana (G2) uses oil palm kernel shells in its sophisticated gasifier from All Power Labs (USA) as they are readily available in the northern part of Ashanti Region where the plant is located and have been approved and tested - according to the manufacturer's website. They are not, however, consistently sized and cannot be loaded and stacked within the reactor in the same way as wood chips or pellets. As a consequence, the capacity of the installed blower has turned out to be insufficient to ensure proper through-flow of syngas through to the engine. For the time being the system is out of service, pending an upgrade to the primary blower. At the Husk Power Systems (Indian) gasifier installed by Pamoja Cleantech in Uganda (G4), whole maize cobs are fed to the reactor and the lack of chipping (along with poor air management) is thought to be contributing to low reactor temperature and high levels of tar and particulate matter in the syngas.

Most gasifiers are intolerant of mixed feedstocks and this prevents operators from blending different biomass streams according to local availability. At Kilombero Plantations in Tanzania (G6), for example, there are competing demands for a limited supply of rice husks - not only for the company's 0.5 MW Chinese gasifier, but also for the furnaces that power its rice dryers - meaning that the system has been run only intermittently for a total of just 50 days over the last two years. Maize residues are seasonally available but cannot be blended with the rice husk in the same feedstock stream. The gasifier would have to be stopped and restarted to take this second fuel, under a different management regime. This experience demonstrates the impact that narrow feedstock specifications have on attempts to balance available supplies of appropriate feedstock.

A similar problem has been encountered at the UNIDO[10]-supported gasifier in Nigeria's Ebonyi State (G3) because the Indian equipment has been optimised for a particular type and size of pre-cut wood chunks. The State Government has developed funding proposals for additional gasifiers that can use rice husk instead, but the two fuels cannot be blended in the existing plant unless it is shut down and re-started before each fuel switch.

At the Novis GmbH gasification project at Kalom in Senegal (G1), an unforeseen rise in the price of peanut shells and a squeeze on availability were major factors in the shut-down of the project, given again that alternative feedstocks could not simply be fed to the gasifier (had they even been available, with the shells already being

[10] United Nations Industrial Development Organisation.

sourced from peanut oil factories up to 50 km away). No long-term supply contracts were in place with the suppliers to enforce feedstock price and quantity specifications.

To avert the problem of shortage and price variation, the Cummins Co-Generation plant in Kenya (G5) has adopted a community sourcing model for its intended feedstock, which is wild-harvested *Prosopis juliflora*, an introduced tree species that has become highly invasive in Kenya's drylands. Prosopis branches supplied by community groups are dragged to central collection points then trucked to the Cummins yard where they are stored for chipping. DFID support under the regional Renewable Energy and Climate Adaptation Technologies (REACT) programme enabled Cummins to set up legally-binding supply contracts with six community-based organisations, with the price pegged according to the moisture content of the wood. The system is yet to be tested, however, as the project is still in pre-commissioning phase due to technical problems with the gasifiers.

Sensitivity to feedstock specifications and a requirement for homogeneity mean that gasification is a far less flexible technology than biogas (or indeed other combustion-based systems). It does not permit a variety of available feedstocks to be used and this limitation restricts the potential resource base. While tight supply contracts with clear price and quality specifications can in theory address the issue, in practice these are difficult to enforce.

Barrier 2: Technology limitations

All six gasifier projects face significant technology-related problems and none has operated continuously for more than 8 to 10 hours at a time. This confirms the conclusions of a 2012 GIZ study (see earlier footnote reference) that "*there is not yet any reliable, affordable standard gasifier technology appropriate for rural small-scale applications readily available of the shelf*".

The fact that most gasifier manufacturers provide no performance guarantees or service warranties perhaps reveals their own lack of confidence in the performance capabilities of their equipment in SSA operating conditions. All Power Labs represents an exception as it does provide a two year warranty. Being based in California, however, it is hard to see how this warranty can be honoured and there is a history of the company's equipment breaking down within a matter of months or even hours at sites in Uganda, Liberia, Chad and Ghana (the site of the KITA Case Study [G2]). Spares can always be sent to Africa but in-person technical back-up is far harder to deliver.

The gasifiers observed in the field are sensitive to feedstock characteristics, reactor feeding rates and operating load. If working conditions are not absolutely in line with manufacturer specifications, then high tar and particulate matter levels inevitably

contaminate the syngas. The immediate result is poor performance of the connected engine, while in the longer term a significant toxic waste disposal problem is created as contaminated scrubbing water and filter materials (such as sawdust, rice husk, activated charcoal and cloth membranes) must then be safely disposed of.

Wet gas cleaning systems are used at five of the gasifiers while the All Power Labs unit in Ghana (G2) employs a dry system. No site has a safe means of disposing of contaminated water and filters, and these are dumped adjacent to the plants leading to a considerable environmental hazard. This is a supressed problem because none of the systems has been operational for any significant period - the highest being a cumulative 50 days at Kilombero Plantations (G6), where tar has reportedly been used to fill in potholes on farm tracks.

The compact gasifier from All Power Labs aims to address the challenge of unstable operating conditions through an automated, computer-controlled approach with a dry gas cleaning system. This represents a more sophisticated design than the Indian systems from Ankur Scientific (G1), IISc Bangalore (G3) or Husk Power Systems (G4). The All Power Labs unit installed in Ghana (G2) can run at close to 950°C and theoretically delivers clean gas to the built-in engine, whereas the simple but more robust Indian equipment from Husk Power Systems installed by Pamoja Cleantech in Uganda (G4) has been running at only 500-600°C, resulting in an inevitable requirement for a series of cleaning cyclones, scrubbers and filters before the syngas can enter the engine. The tar and particulate matter levels at the All Power Labs gasifier are not known, however, making it difficult to draw final conclusions of the effectiveness of its more sophisticated design.

Notwithstanding the gas cleaning challenges with the Indian equipment, these simpler systems have achieved longer operational times in SSA than All Power Labs gasifiers. The system in Ghana (G2) has only operated for 56 hours and other gasifiers in SSA from the same supplier have broken down after no more than a few hundred operational hours[11]. Even the high spec three-line gasification plant of Cummins in Kenya (G4) supplied by a specialist manufacturer from the Dominican Republic, is producing syngas with excessive tar and particulate matter at levels that the in-built cleaning system is unable to reduce sufficiently for the two installed gas engines. This major 2.4 MW_e system has yet to be commissioned, despite an investment to date believed to exceed USD 2 M.

The problematic build-up of tar and particulate matter in the gasification process is also affected by the load at which the gasifier is operated. These units are designed

[11] A second unit was installed in Ghana in early 2017 at Tamale, but operating status is unknown.

to operate most effectively at the manufacturer's rated capacity. Operating at lower load factors results in higher tar build-up and a more challenging clean-up process[12]. Power output must be therefore matched with both the timing and the size of anticipated demand, which is a significant challenge.

In the rural setting of central Uganda, where Pamoja Cleantech has installed a 32 kW_e gasifier, demand from a mini-grid connected to 72 homes is no more than 7.5 kW_e. This is well below the gasifier's lowest turn-down level of 40% (13 kW_e) and the operator reports that the grid is no longer viable for both technical and economic reasons. The opposite situation exists at the UNIDO gasifier in Nigeria (G3), where the local trading centre requires at least 1 MW of electricity but available power from the system is only 25 kW_e. The mis-match problem was overcome in Kalom Senegal (G1) by operating the plant at full load for 4 hours every six days and storing the electricity in a battery bank. This plant struggled with inconsistent production of gas that was manually fed into the engine, however, leading to a frequency variation between 45 and 60 Hz which in turn risked damaging other system components.

In summary, the gasifiers at the Case Study sites have proven highly sensitive to operational parameters such as feedstock quality, consistency, feed rate and air control. If these are not in line with precise manufacturer specifications then there is a likelihood that sub-optimal temperatures will be achieved in the reactor chamber and this can result in high outputs of char, tar and particulate matter. These can in turn cause a series of knock-on problems with cyclones, scrubbers, filters, precipitators and engines, and generate a serious toxic by-product disposal problem. Meanwhile small-scale gasification lacks the same degree of power despatchability as other energy technologies for off-grid use, making mis-matches in timing and scale between power output and power demand problematic and requiring a gas storage system, a battery bank or a supplementary power source for periods of downtime.

These technology constraints are not new issues and have been the focus of equipment development for several decades already. Taken along with the other inherent challenges associated with gasification, they represent a significant barrier to replication in SSA.

Barrier 3: Lack of viable business models

The sustainability of a gasifier for providing power to a community or industry requires a commercial model in which a sufficient number of consumers pay a viable price for the electricity received. This requires careful site selection with at least one

[12] GIZ, 2012, as referenced previously.

guaranteed anchor customer, operating for at least several hours per day regularly, who can achieve a saving by switching from their (usually) diesel-powered operation to electricity from the new system.

At Kalom in Senegal (AD1) and the Pamoja project in Uganda (AD4), the envisaged anchor loads did not materialize and demand from households (and thus revenue) was insufficient to cover operational costs. Households in Senegal (G1) refused to pay an agreed tariff of almost USD 1/kWh as electricity production from the gasification unit was reportedly judged too unreliable. Along with rising prices of feedstock, this eventually led to the suspension of the project. The KITA project in Ghana (G2) was not even set up to charge for electricity and the associated oil palm husking and milling facility was not owned by a commercial entity, hence no electricity payment would come even from the supposed 'anchor load'.

The Case Study projects are also fully reliant on power production and no other outputs. A sustainable business model would valorise not only the electricity but also potentially the engine and exhaust heat and possibly the char from the gasifier. Heat valorisation would again require careful site selection with existing productive users that would gain financial benefit from replacing diesel or kerosene-powered boilers.

All six Case Study projects were financed to some extent with donor funds and there is evidence that this has resulted in unrealistic commercial models. Capital costs were fully donor financed without any conditionalities at the projects in Senegal, Ghana, Nigeria and Uganda (G1 to G4), while in Senegal and Ghana some operational costs such as salaries were also grant-funded. The 2.4 MW_e gasifier at Cummins in Kenya (G5) and the 0.5 MW_e unit at Kilombero in Tanzania (G6) were partly funded through development budgets, though indirectly and at a much lower level[13].

The greater the proportion of grant finance, the lower the likelihood that project operators have a vested financial interest in the successful operation of the plants. This represents a major barrier given the complexity and regular system failures that require a positive, problem-solving attitude. It is essential that a managing entity has a financial stake in the project and gains financial benefit from successful operation, confirming the conclusion of a 2012 GIZ assessment (cited previously) which recommended a donor model under which technology providers should only be paid on the basis of electricity produced.

Gasification for energy access in community-based settings is a complex proposition and it seems to be a commercially non-viable technology, based on the barriers

[13] REACT supported the establishment of the community sourcing system for Cummins, while the DFID-supported agri-business fund AgDevCo has a 10% stake in the Kilombero holding company and thus indirectly funded its gasification plant.

documented. The situation is not being helped by the repeated channelling of donor funds to more equipment, without any risk-sharing with technology providers. Solar PV home systems or mini-grids represent a more reliable and appropriate technology in a community setting, and indeed such a system was eventually installed to replace the failed gasifier project at Kalom in Senegal (G1). Even above community-scale, neither the 500 kW_e gasifier at Kilombero (G6) and the 2.4 MW_e Cummins unit in Kenya (G5) have so far been successful, though in theory they represent a more promising model as financial capacity could allow both companies to employ well-trained engineers, demand and supply could be well matched and both electricity and heat could be valorised. The reality of the two projects, however, looks rather different as accessing spare parts and retaining competent engineers in a remote location still represent considerable challenges.

Barrier 4: Limited operator technical capacity

Gasification is a complex process operating to specific technical parameters. The feedstock requirements and operating conditions in the gasifier must be well understood and carefully managed to minimise unwanted production of char, tar and particulate matter in favour of syngas. Polluting outputs, especially tar, have the potential to cause environmental contamination if not carefully treated, while impure gas will affect the performance of engines and result in early breakdown.

It is highly challenging to secure the skills required to operate these systems in the rural and potentially remote locations where they are typically installed in SSA. Both Novis GmbH, the company that developed the gasification project in Senegal (G1) and Pamoja Cleantech, the owner of the Husk Power Systems gasifier in Uganda (G4), succeeded in recruiting or training an engineer based in the respective capital city to address some operational issues. In the case of Novis, a German-trained Togolese engineer was responsible for overall operation, while in Uganda, a local engineer spend one year on exchange in India with Husk Power Systems. Finding day-to-day operators in rural settings has, however, proven significantly more challenging and better trained engineers are unlikely to stay long-term in these locations. Besides the right skills level, it is crucial that the operator and capital-based engineer are well motivated to overcome the myriad barriers that they will inevitably encounter with the operation of a gasifier in a rural SSA setting. In short, there are very few qualified individuals who understand gasifiers and can run them properly, compounding the problem of reliability and reputation that plagues the sector.

Barrier 5: Poor access to manufacturer support and spare parts

There is no known African manufacturer of gasification plants and equipment at the Case Study sites has been imported from India, China, the USA and the Dominican Republic. Only Husk Power Systems (India) has representation on the continent, via a

newly established office in Dar es Salaam that services a number of donor-financed mini-grid installations in Tanzania. There is hence extremely limited access to technical support or spare parts for gasifiers in Africa. Kilombero Plantations (G6) installed a gasification system from a Chinese company that has no local agent, for which replacement parts have had to be imported. All Power Labs (USA) employs one maintenance engineer globally, which is proving insufficient to provide responsive site support. Manufacturers also provide no meaningful performance guarantees, although Cummins (G4) is reportedly withholding partial payment from its equipment supplier until the gas quality problem is resolved.

It could be argued that none of the small-scale gasifier manufacturers currently has an incentive to invest in providing more reliable support from local agents as long as equipment is being paid for through sporadic and unpredictable grant awards. Orders are largely unconnected to the successful operation of previous units and demand does not reflect any wider commercial upsurge in demand for this type of technology in SSA. Nevertheless, the widely experienced operating problems across a variety of international equipment suppliers are having negative effects on perceptions of gasification as a technology option, and without proper technical back-up on the continent to change things around it is likely that the reputation of gasification is only likely to worsen.

3.3.3 Summary

Gasification technology in SSA faces major commercial and technical challenges and no project could be identified that was functioning reliably. Of the six promising sites on the continent that were visited, four community-based gasifiers have been mothballed for lack of commercial viability or technical problems, another is dormant due to lack of feedstock (Kilombero Plantations in Tanzania [G6]) and the sixth (Cummins Co-gen in Kenya [G5]) is yet to be commissioned due to gas cleaning problems.

These significant difficulties reflect the study team's earlier findings on gasification that were reported to DFID in the TVC Prioritisation Report, in which it was concluded that the technology has a 100% failure rate in Africa at small output scales and that state of the art systems are complex to maintain, while simpler equipment is proving both polluting and unreliable. The technology was retained for the Case Study phase in order to explore opportunities for innovation that could potentially be addressed through BSEAA-supported research. Having completed this analysis, however, the prognosis for research-supported solutions is not encouraging as the range and severity of barriers is so significant.

3.4 Sub-1 MW steam turbines

During the previous phase of the BSEAA study, combustion-based steam turbines were not taken forward for Case Study analysis owing to the lack of operational examples at a micro- to small-scale in SSA. With DFID's endorsement, a free-standing piece of research was instead conducted to analyse small-scale steam turbine technology more closely on the basis of technological efficiency and economic competitiveness. The aim was to provide a better understanding of the challenges facing adoption of steam turbines at a sub-1 MW scale, and to indicate areas of potentially useful research based on the findings. The full report may be found in 0.

The study confirmed the poor technical efficiency of steam turbines in comparison to alternative technologies at sub-1 MW output levels, for a number of inherent technical reasons. Ongoing research into improved combustion systems for boilers, better heat transfer and aerodynamics to improve turbine blade life and performance, and improved materials to permit longer life and higher operating temperatures may offer marginal improvements to the performance of small-scale turbine plants.

The economic analysis suggests there may be value in conducting feasibility assessments for retrofitting steam turbines for CHP in agri-businesses that have both a functioning heat generation system and a significant electricity demand. Of the ten countries prioritised for BSEAA, such research would be most useful in Ghana, Kenya and Rwanda, where the cost of electricity for industrial use appears to be higher than the upper estimates of the Levelised Cost of Electricity from steam turbines.

4. Opportunities for Research

4.1 Introduction

According to the BSEAA Business Case, the research activities to be supported under Phase II should respond to the commercial, economic and technical challenges that have been identified to the deployment of bioenergy in SSA by identifying, testing and piloting appropriate solutions on the ground. The Phase I Terms of Reference make clear that the development of technological solutions to these challenges will be prioritised over other potential options.

Is therefore assumed that:

- DFID intends to develop a call for proposals in Phase II that directly address the barriers identified in this report;
- The focus will be on those barriers that can be addressed by research; and
- Research that addresses technological barriers will be prioritised.

In defining the limits of the anticipated call, the study team proposes a focus on **anaerobic digestion**. The previous BSEAA deliverable (the TVC Prioritisation Report) already makes a strong case for anaerobic digestion as the most promising technology for further research in SSA, with innovation potential in technology, feedstocks and business models. The Case Study phase has confirmed the growing commercial investment in SSA's biogas sector, to which DFID could add impetus through targeted research. The technology has high adoption levels outside the continent from which to draw lessons and leapfrog technologically, offers significant feedstock flexibility across municipal, agricultural and livestock waste streams, produces despatchable energy and brings co-benefits from waste disposal and fertilizer production.

The TVC Prioritisation Report meanwhile noted that **gasification** has a poor track record at small output scales, and that state of the art systems are complex to maintain, while simpler technologies are proving both polluting and unreliable. Failure rates in SSA are close to 100% due to problems with gas quality, lack of maintenance expertise and spare parts, and absence of economic viability. Case Study research into the small number of plants known to exist in SSA has confirmed this discouraging prognosis and confirms previous analyses by GIZ and the World Bank. The barriers to replication are so significant and wide-ranging that there is no realistic opportunity for research to make a difference to replication potential. It is therefore proposed that gasification-related research is not supported in Phase II.

An absence of small-scale **steam turbines** prompted desk research into the technical and economic feasibility of sub-1 MW heat or power applications and potential

innovation opportunities. This has revealed some potential for retrofitting steam turbines for CHP in agri-businesses that have both a functioning heat generation system and a significant electricity demand. Further feasibility research on this theme is a supplementary option for BSEAA Phase II.

4.2 Research opportunities in anaerobic digestion

Table 4 summarises the six identified barriers to the wider adoption of industrial anaerobic digestion in SSA.

Table 4. Barriers to the replication of industrial-scale anaerobic digestion in Sub-Saharan Africa

1. Unreliable feedstock supply
2. Costly and insufficiently adapted technology
3. Limited operation technical capacity
4. Lack of viable business models
5. Unfavourable policy and regulation
6. Limited access to manufacturer support and spare parts

A wide variety of research ideas will doubtless be proposed under the Phase II call. Without wishing to pre-empt these submissions, some indications of potentially relevant research themes are elaborated below for each barrier.

Barrier 1: Unreliable feedstock supply

Investigation into biomass resources across the prioritised BSEAA countries to quantify available feedstocks by identifying concentrated sources under clear ownership, evaluate suitability (including combinations where available) and elaborate business models for their application in biogas systems. Feedstocks could include by-products from agriculture, agro-industry, livestock and municipal waste systems, as well as wild-harvested biomass, and might be seasonal. Such research could build on existing resource studies for specific African countries.

Exploration of the biogas productivity potential of novel feedstocks and feedstock blends, particularly those unique to Africa. Biomass from marginal drylands could be particularly interesting, including CAM plants. Social and environmental implications would need to be considered, including potential competition with existing uses and food production.

Technical and commercial feasibility assessment of methods for breaking down lignocellulosic feedstocks for anaerobic digestion, to expand the volumes of biomass potentially available for use in African biogas systems and increase biogas yields (taking into account competing uses and values).

Barrier 2: Costly and insufficiently adapted technology

Development of modified versions of European biogas technology to achieve cost reduction through design adaptation, while retaining functionality and reliability, to increase affordability and adoption rates in SSA. This should include customisation to suit African regional climates, seasonality differences, feedstock variation and other operating realities, to increase appropriateness and performance. Standardised African plant designs may result for particular feedstocks and operating environments.

Barrier 3: Limited operator technical capacity

Research into structures that could enhance interaction and mutual support between biogas plant operators, to establish a core of technical expertise for operating modern industrial biogas systems in SSA, building on experiences from other sectors. This could be linked to research into current training provisions within academic, vocational and technical institutions, with recommendations on how to develop a more industry-relevant system for developing operating and maintenance capacity.

Barrier 4: Lack of viable business models

Development of a financial modelling tool for evaluating potential biogas projects at new sites in SSA, in which multiple income streams (including electricity, heat, fertilizer and waste disposal) can be valorised to explore the commercial potential of different models. This could extend to exploring financing opportunities to bring promising opportunities closer to realisation.

Research into models of donor support for the biogas sector that ensure commitment of project developers to commercial success, with meaningful sharing of risk, and ways to maximise community or pro-poor impact.

Development of creative approaches for increasing commercial lending to biogas projects, drawing on successful financing models from other sectors, and including partnerships between development agencies and financial institutions to de-risk lending. Cooperation with initiatives such as PFAN or the Finance Catalyst of RECP is suggested.

Barrier 5: Unfavourable policy and regulation

Financial modelling to explore the impact of different policy measures on a range of biogas configurations, considering various heat and digestate valorisation scenarios,

to help guide policymakers towards realistic regulatory and tariff structures (e.g. for electricity grid feed-in) that will support growth of the industry. This could include modelling of the implications of effective enforcement of environmental regulations on the commercial case for biogas projects in SSA.

Barrier 6: Limited access to manufacturer support and spare parts

Advocacy-oriented research into the social, economic and environmental case for governments to support the development of a biogas industry in SSA countries, including co-benefits of waste disposal, fertilizer production, industrial development and job creation, to create a supportive environment for industry to invest and thus increase the access to manufacturer support and spare parts.

4.3 Research opportunities in steam turbines

Steam turbines have low efficiency at sub-1 MW scales in comparison with other available technologies for a number of inherent technical reasons. Ongoing industry research may offer marginal improvements to performance at these scales so there is not thought to be added value from DFID offering additional support to this.

Economic analysis suggests some potential for retrofitting steam turbines for CHP at existing agri-businesses that have both a functioning heat generation system and a significant electricity demand. Of the ten countries prioritised for BSEAA, such research would probably be most useful in Ghana, Kenya and Rwanda, where the cost of electricity for industrial use appears to be higher than the upper estimates of the levelised cost from steam turbines. There may be value in conducting feasibility assessments in those countries to verify this opportunity. This is a decision for DFID to take, balancing the risk of diluting the resources otherwise available for biogas research with the benefits of exploring a niche opportunity for steam turbine development.

4.4 Summary of implications

Successive phases of BSEAA research have led to the conclusion that anaerobic digestion is the bioenergy technology which offers the greatest potential for replication in SSA at the sub-5 MW output scale, supported by evidence from successfully operating projects. Indications of potential research themes to address the identified barriers have been suggested, and the Phase II call will no doubt elicit a wider variety of ideas that DFID can screen for relevance and impact potential. DFID may also wish to focus on a sub-set of the barriers in framing its call, to maximise the impact of available resources. The research could be undertaken by technical, academic or private sector organisations acting alone or in consortia, or even by establishing a Centre of Excellence for applied biogas research in Africa, in

partnership with industry. Cooperation with other donor programmes such as the Africa-EU Renewable Energy Cooperation Programme would be valuable to maximise effectiveness and reach.

The barriers facing gasification are meanwhile too significant and wide-ranging for research to make a significant difference to uptake. Gasification-related research is therefore not deemed worth supporting in Phase II.

It is left for DFID to decide if feasibility research into the retrofitting of sub-1 MW steam turbines to any existing CHP plants in Ghana, Kenya and Rwanda represents a useful addition to the Phase II call, balancing the dilution of research resources for biogas against the benefits of exploring this lesser opportunity.

Annex A Mission itineraries and people met

Mission 1: East and Southern Africa

Date	Time	Activity	Name	Position	Organisation
Mon 8 May	21:55-13:35	Ralph fly London-Entebbe			
	06:20-22:20	Matthew fly Bristol-Entebbe			
		Overnight Kampala			
Tue 9 May	08:30-09:00	Meet biogas specialist	Geert Jan Heusinkveld	MD	Q Energy
	09:15-11:30	Visit Kampala abattoir AD plant	Dr Joseph Kyambadde	Senior Scientist	Dept. of Chem Eng, Makerere Univ.
	11:45-13:15	Meeting at PAMOJA Cleantech	Nicholas Fouassier	CEO	PAMOJA Cleantech
	13:15-15:00	Drive Kampala-Sekanyoni			
	14:00-16:00	Visit PAMOJA/Husk Power gasifier, Magara village, Ssekanyonyi, Mityana District	Raymond Lumansi	Technical Manager	PAMOJA Energy Ltd.
	16:15-18:00	Drive Sekanyonyi-Entebbe			
	21:40-22:50	Fly Entebbe-Nairobi and overnight			
Wed 10 May	09:30-10:30	Meet KPMG (AECF REACT fund manager)	Anjali Saini	Adviser	AECF REACT
	11:00-12:00	Meet RECP research lead	Matt Woods	Director	Carbon Africa
	15:40-16:30	Fly Nairobi-Kisumu			
	17:00-19:00	Drive to Kericho and overnight			
Thu 11 May	08:00-11:00	Visit James Finlay Kenya AD plant, Saosa, Kericho	Hugo Douglas-Dufresne	Technical Director	James Finlay Kenya
			Dennis Cheruiyot	Biogas Site Manager	
	11:00-14:30	Drive Kericho-Marigat			
	14:30-16:0	Visit Cummins Co-gen gasifier, Marigat	John Kamau	Mgmt. Accountant	Cummins Co-Gen (Kenya)
			Nichodemus Mutua	Technician	
			Jemima Jerop	Technician	
			Silas Tisgol	Technician	
	16:00-18:30	Drive to Elmenteita and overnight			
Fri 12 May	08:00-09:30	Drive Nakuru-Naivasha			
	09:30-13:00	Visit Tropical Power AD plant, Gorge Farm, Naivasha	Mike Nolan	Operations Director	BioJoule Kenya

Date	Time	Activity	Name	Position	Organisation
	13:00-16:00	Drive Naivasha-Makuyu			
	16::00-18:00	Visit Olivado AD plant, Murang'a	Hannes Mutingh	Biogas Manager	Olivado Kenya
	18:00-20:00	Drive to Nairobi and overnight			
Sat 13 May	10:00-11:00	Meet LTS Africa	Scott Geller	Director	LTS Africa
		Overnight Nairobi			
Sun 14 May	15:25-16:50	Matthew fly Nairobi-Dar			
	19:35-21:00	Ralph fly Nairobi-Dar			
		Overnight Dar			
Mon 15 May	09:00-10:00	Meet Husk Power Systems	Athina Kiriakopoulou	Country Director	Husk Power Systems
			Guillem Gomis	Operations Manager	
			Anil Kumar	Snr. Biomass Technician	
	12:00-13:00	Meet DFID Tanzania	Leanne Jones	Climate & Envt. Adviser	DFID
		Overnight Dar			
Tue 16 May	08:30-09:30	Meet KMPG (ex-AECF REACT)	Mary Batterman		KPMG
			Damian Casmiri		
	12:00-13:30	Fly Dar-Kilombero			
	14:00-16:00	Visit KPL gasifier with AgDevCo, Mngeta, Kilomber	David Arnott	Deputy MD	Kilombero Plantations Ltd.
			John Kiragu	Power Manager	
			Tom Mukanda	Biomass Technician	
			Peter James	Snr. Investment Mngr.	AgDevCo
	16:00-23:30	Drive Kilombero-Mikumi and overnight			
Wed 17 May		Cancelled visit to Husk Power gasifier, Kibindu village, Coast Region			
	09:00-17:30	Drive Mikumi-Tanga and overnight			
Thu 18 May	08:15-09:30	Drive Tanga-Hale			
	09:30-11:30	Visit Katani AD plant, Hale sisal estate, Tanga Region	Francis Nkuba	Executive Director	Katani Ltd.
			Mr Magogo	Planning Manager	
			George Kasese	Chemist	Mkonge Energy Systems
			Elisha Cheti	Mechanic/Technician	
	12:00-13:00	Drive Hale-Tanga			
	15:25-17:05	Fly Tanga-Dar and overnight			AuricAir
Fri 19 May	a.m.	Case study write-ups			

Date	Time	Activity	Name	Position	Organisation
	12:00-13:00	Meet local gasifier developers, Ubungo	Fadhil Sadik	Technical Director	Space Engineering Co.
			Emrod Elisante	Director	Innovation & Tech Exchange Centre
	15:35-18:10	Fly Dar-Johannesburg			SAA
	20:30-22:00	Meet GIZ, Rosebank	Sofja Giljova	RE Adviser	SA-German Energy Programme
		Overnight Johannesburg			
Sat 20 May	08:30-10:00	Meet biogas developer, Rosebank	Rob Cloete	Managing Director	Selectra
	10:30-11:30	Meet EEP advisor, Rosebank	Darius Boshoff	Managing Director	ENERGiDrop
	15:10-16:15	Fly Jo'burg-Durban			
	17:00-18:30	Drive Durban-Pietermaritzburg & overnight			
Sun 21 May		Case study write-ups			
		Overnight Pietermaritzburg			
Mon 22 May	08:00-10:00	Visit Sunshine Seedlings AD plant nr. Pietermaritzburg	Mike Smith Warren Confait	Directors	Renen Energy Solutions
	10:00-12:30	Drive Pietermaritzburg-Mandini			
	12:30-15:00	Visit SucroPower AD plant, Thorny Park, Mandini	Nic Bennett Errol Watt	Directors	SucroPower
	15:00-16:00	Drive Mandini-Durban			
	17:40-19:55	Fly Durban-Cape Town and overnight			Mango
Tue 23 May	10:00-11:00	Meet former PAC energy specialist, Woodstock	Ewan Bloomfield		
	12:30-14:00	Meet LTS Project Manager, Chiappini St.	Benoît Rivard		LTS International
	17:00-18:30	Meet Citius Energy, Green Point	Anthony Williams	CEO	Citius Energy
		Overnight Cape Town			
Wed 24 May	09:00-10:00	Meet Anaergia, Green Point	Dennis Thiel	VP Sales	Anaergia
		Case study write-ups			
	19:30-06:30	Ralph fly Cape Town-London			British Airways
	23:00-13:15	Matthew fly Cape Town-Bristol			KLM

Mission 2: West Africa

Date		Time	Activity	Name	Position	Organisation
Mon 19 Jun		11.35-20.40	Ralph fly London-Dakar and overnight			Iberian
Mon 19 Jun		09:20-19:25	Matthew fly Bristol-Lagos and overnight			KLM
Tue 20 Jun	RR	09:00-14:30	Drive Dakar-Kolum			
Tue 20 Jun	RR	14:30-18:00	Visit Novis gasification project, Kalom village	Mawulolo A. Glikpa	Project Engineer	(former) Novis GmbH
				Woula Ndiaye	Senateur of the village	Kalom village
Tue 20 Jun	RR	18:00-21:30	Drive Kolum-Dakar and overnight			
Tue 20 Jun	MO	08:30-09:30	Fly Lagos-Enugu (delayed 1 hr)			Air Peace
Tue 20 Jun	MO	09:30-10:30	Drive Enugu-Abalkaliki			
Tue 20 Jun	MO	10:30-10:45	Meet Ebonyi State Government	Dr Chamberlain Nwele	Acting Secretary	Ebonyi State Government
Tue 20 Jun	MO	10:45-11:15	Drive Abakaliki-Ikwo Industrial Cluster			
Tue 20 Jun	MO	11:15-12:15	Visit Ebonyi State gasifier project, Ikwo Industrial Cluster, Ngbo Clan	Elom Chukwuma	UNIDO Projects Coordinator	Ebonyi State Government
				Eng. Ituma Ikenna	Chief gasifier project engineer	
				Eng. Emmanuel Emeka	Gasifier project engineer	
Tue 20 Jun	MO	12:15-13:15	Drive Ikwo-Enugu			
Tue 20 Jun	MO	14:45-16:00	Fly Enugu-Lagos and overnight			Air Peace
Wed 21 Jun	RR	08:30-09:00	Drive to abattoir			
Wed 21 Jun	RR	09:00-12:30	Visit Theogas Abattoir Project, Dakar	Lamine Ndiaye	Director	Thecogas/Compagnie 3e
Wed 21 Jun	RR	15:25-22:00	Fly Dakar-Accra and overnight			
Wed 21 Jun	MO	08:30-10:00	Drive Lagos-Ogun State			
Wed 21 Jun	MO	10:00-11:30	Visit Avenam Links AD plant, McNichols farm, Papa, Ogun State	Nina C. Ani	CEO	Avenam Links International
				Dr Wale Salako	Head of farm & vet doctor	McNichols Consolidated farm
				Zaccheaus Olawoyin	Biogas plant manager	
Wed 21 Jun	MO	11:30-13:00	Drive Ogun State-Lagos			
Wed 21 Jun	MO	15:10-15:10	Fly Lagos-Accra and overnight			Africa World Airlines
Thu 22 Jun		Attend ECOWAS/GBEP Energy Week, Accra				
Fri 23 Jun		Attend ECOWAS/GBEP Energy Week, Accra				

Date	Time	Activity	Name	Position	Organisation
Sat 24 Jun	08:30-09:00	Drive Accra-Ashaiman			
	09:00-11:30	Visit Safi Sana biogas plant, Ashaiman	Raymond Okrofu	Country Manager	Safi Sana Ghana Ltd.
	11:30-12:00	Return from Ashaiman-Accra			
	p.m.	Case study write-ups; overnight Accra			
Sun 25 Jun	All day	Case study write-ups; overnight Accra			
Mon 26 Jun	08:30-10:00	Drive Accra-Adeiso (Eastern Region)			
	10:00-14:00	Visit HPW AD plant, Adeiso	Maik Blaiser	Managing Director	HPW Fresh & Dry Ltd.
			Shadrack Ofori	Environmental Officer	
	14:00-15:30	Drive Adeiso-Accra			
	17:15-17:55	Fly Accra-Kumasi and overnight			Starbow Airlines
Tue 27 Jun	09:00-11:00	Drive Kumasi-Papasi			
	11:00-13:00	Visit KITA gasifier, Papasi, Offinso North District	Benjamin Boahen	Technical Adviser	Centre for Energy, Envt. & Sust. Dev't.
			Alhassan Bome	Operator	
	13:00-15:00	Drive Papasi-Kumasi and overnight			
Wed 28 Jun	10:30-11:30	Visit KNUST energy researcher, Kumasi	Michael K. Commeh	Research Fellow	KNUST Tech Consultancy Centre
	13:10-13:50	Fly Kumasi-Accra			Starbow Airlines
	p.m.	Case study write-ups			
	22:00-08:50	Matthew Fly Accra-Bristol			KLM
	22:35-06:15	Ralph Fly Accra-London			British Airways

Mission 3: Germany and UK

Date	Time	Activity	Name	Position	Organisation
Tue 4 July	07:20-12:30	Train Konstanz to Freising			
	12:30-16:30	Meeting at the German Biogas Association	Clemens Findeisen	Advisor Development Corporation	German Biogas Association
			Antje Kramer	Project Manager	German Biogas Association
			Walter Danner	CEO	Snow Leopard
			Paul Okanadjetey	Former Project Manager	German Chamber of Commerce, Ghana
	20:00-01:00	Flight Munich-London			
Wed 5 July	8:00-10:00	Train London-Birmingham			
	10:00-18:00	Attend World Biogas Expo 2017	Stephan Hoffmann	Head of International Sales	PlanET
			Erwin Koeberle	Director	Biogaskontor Koeberle GmbH
			Hugh Richmond	Head of Global Sales	Edina
			Dr Sarika Jain	Research and Policy Manager	World Biogas Association
Thu 6 July	10:00-16:00	Attend World Biogas Expo 2017	Owen Yeatman	Director	Farmergy
			Marcel ter Beek	Sales Manager	wiefferink
			Jon Hawkins	Sales Manager Small Steam	Siemens
			Marcus Dosdworth	Technical Sales Executive CHP	Shentongroup
			Dr Melanie Hecht	Process Engineering Advisor	Schaumann BioEnergy
	16:00-17:30	Train Birmingham-London			

Annex B Country Scoping Reports

Introduction

The study team had initially proposed that the Case Study visits to countries in Africa would be preceded by 'Country Scoping Missions'. These 3-4 day visits were to be conducted by the Team Leader to a maximum of five countries in order to confirm that the proposed case studies would be appropriate and viable, and that project developers on the ground would be willing to engage and collaborate. The scoping visits were to be followed by in-depth data gathering missions to conduct the Case Study analyses themselves. The result was to be a set of short Country Scoping Reports that would precede the production of stand-alone Case Study Reports.

This proposal for two rounds of country visits and reporting was re-evaluated during study implementation. The idea had been based on the assumption that only one Case Study would be required for each TVC, meaning a total of only three to five Case Studies in total. It was realised during the stakeholder mapping phase, however, that such a small sample would yield insufficient insight into the barriers and opportunities facing the deployment of particular TVCs. It would also be risky to rely on so few Case Studies for evidence, in case a venture was no longer operational or if those involved could not provide sufficient information to build up a profile. It was therefore proposed that additional TVC examples should be included in the analysis, necessitating longer Case Study missions covering more countries.

Given the time and cost implications of this lengthier period of field research, it was suggested that pre-planning for the Case Study missions should now be conducted remotely from the UK, in order to adhere to the same budget and timeframe. DFID approved a proposal to merge the Country Scoping and Case Study work, and to combine the two deliverables. The 'Country Scoping Reports' published in this Annex are now brief summaries of the side meetings that were held during the country missions (outside the case study site visits). These meetings allowed the study team to take advantage of their travels to SSA countries of interest to DFID to engage with bioenergy sector experts to seek their views and ideas.

The meeting summaries are arranged chronologically. The schedule of meetings and list of people consulted has been provided separately in Annex A.

Summary of regional consultations

Uganda: Q Energy Consultants

Q Energy Biodigesters is a Dutch company that entered the Uganda market with the aim of exploiting opportunities for marketing small-scale biogas systems. This did not prove viable and the company is withdrawing from equipment sales to concentrate on energy consulting and advisory services. The investors behind Q Energy do not believe there is currently sufficient commercial demand for small-scale biogas systems in Uganda, despite significant investment (especially via the Dutch-funded programme Africa Biogas Partnership Programme) in domestic installations designed to provide gas for cooking and lighting.

Kenya: KPMG

KPMG was the fund manager for the Africa Enterprise Challenge Fund's Renewable Energy and Adaptation to Climate Change Technologies (AECF REACT) window until April 2017. Management has recently moved to a newly-formed entity known as AECF Ltd.

REACT is a competitive fund open to business ideas based on low cost clean energy solutions that help smallholder farmers adapt to climate change. Up to 50% grant financing has been offered through a series of competitive calls for ventures at the scale EUR 0.5-1 M. REACT blends funds from DFID's Africa Regional Department, DFID Tanzania and DFID Kenya (via StARK+ - Strengthening Adaptation and Resilience to Climate Change in Kenya). A separate REACT fund for Mozambique is funded by Denmark.

Applicant interest in bioenergy has reportedly been low and there have been very few REACT projects designed to generate heat or power from biomass. The BSEAA study team had communicated previously with the REACT team at KPMG. They had kindly facilitated connections to grantees for case study visits to Cummins Co-generation's gasification plant in Kenya and a Husk Power Systems gasification site in Tanzania, as well as catalysing dialogue with Simgas (for biogas for milk chilling in Tanzania). Some applicants for large-scale AD plants had reportedly been turned down on the grounds that REACT funds were unnecessary to make the commercial case. KPMG/REACT had also declined to fund a biogas bottling project at the Keekonyoike abattoir in Kenya because the feasibility study was apparently not plausible.

While there are no immediate plans for a further round of funding under REACT that would include bioenergy, it is possible that a fresh call may take place once the new management arrangements under AECF Ltd. are properly established.

Kenya: Carbon Africa

Carbon Africa has evolved from developing carbon credit opportunities to providing research and advisory services in the energy and climate change sector. It is currently partnering with InTech (Germany) on a three-part project funded by the Africa-EU Renewable Energy Cooperation Programme (RECP). RECP is in turn part of the European Union Energy Initiative's Partnership Dialogue Facility (EUEI-PDF). Managed by GIZ, EUEI-PDF has several service lines and RECP is a framework for strategic dialogue between Africa and the EU aimed at sharing knowledge, setting political priorities and developing joint programmes on the key energy issues and challenges, with a special focus on increasing investment in energy infrastructure. Among other targets, it aims to triple Africa's production of bioenergy by 2020.

Carbon Africa leads Market Information and Project Scouting strand of the RECP project. Partners for Innovation (Netherlands) is meanwhile investigating Access to Finance and Intech is providing Policy Advisory Services. The overall result is expected to be a pipeline of projects, funding possibilities and policy information that add up to a portfolio of investible energy projects in targeted African countries. Carbon Africa will produce a Developer Guide and model business cases as part of the project's attempt to assist potential investors from the earliest feasibility stage to eventual financing.

The project is focussing initially on Zambia, Uganda and Senegal, with plans to expand to Rwanda, Mozambique and Nigeria. Bioenergy is only being considered in Uganda at present, with the emphasis initially on captive power opportunities. The project is investigating investment opportunities in the 100 kW to 5 MW range.

There is significant thematic and geographic overlap with DFID's BSEAA project, though RECP goes further to address a full range of enabling factors for bioenergy projects that go beyond technology. It will be important to ensure that BSEAA Phase II retains close connections to RECP and its implementing agents, especially in the context of Uganda where RECP's portfolio includes bioenergy.

Tanzania: Husk Power Systems

Husk Power Systems (India) is the first gasifier company to establish a permanent presence in Africa and operates from offices in Dar es Salaam. Having installed almost 100 community-scale gasification plants of 30-50 kW in India, it has now sold at least 12 systems of similar size to project developers in Uganda and Tanzania. These projects have struggled to become technical and economically sustainable under local community or NGO management, however, so Husk Power is revising its business model in Tanzania with two main changes. First, it will now install hybrid solar/gasifier mini-grids so that the household baseload can be satisfied with solar power during the day while commercial demand (e.g. from maize or rice mills) can be met from gasifiers operated during the evening. This will avoid generating redundant

gasifier power during the day and spending money on excess battery capacity. Second, it now plans to build, own and operate the mini-grids and sell power to consumers, rather than simply selling equipment to third parties and leaving them to run it themselves. Customers will pre-pay for electricity via mobile money services using remotely controlled Sparkmeter systems. Mini-grids of 150-200 customers are foreseen with a 32 kW (40 kVA) gasifier/engine combination plus 20 kW of solar capacity and 24 2V, 1,500Ah batteries. Three staff will be employed at each site by Husk Power and a customer service team in Dar will provide on-call technical support for the first three months.

A Husk Power gasifier currently costs around USD 80,000 to import and install in Tanzania. It is difficult to see how operation, maintenance and depreciation costs can be covered by small networks of 150-200 domestic consumers, given that demand is likely to be no more than 50-70 W per connection. The evidence will be generated by the first few sites now being developed in Coast Region (Kibindu) and Morogoro Region (Biro). Case Study visits were not possible because neither system is yet up and running.

Husk Power anticipates that previous management challenges can be overcome under the new business model, though acknowledges that technical literacy of consumers will be important as they have to understand the concept of power units and how to pay for them with mobile money, while limited technical capacity of village-based technicians remains a constraint.

Tanzania: DFID

The Climate and Environment Adviser at DFID Tanzania leads the regional REACT project (see above) and also manages national projects on green mini-grids, grid extension and grid densification (with Swedish co-financing) in collaboration with the Rural Electrification Agency. Results-based finance is available for up to 75% of mini-grid costs, based on the number of households connected and the tier of energy service provided (from a maximum of USD 600 per household downwards). While mini-grids with bioenergy theoretically qualify for support, no applications have so far been made for biomass-powered systems.

The DFID Adviser sees barriers to bioenergy development around feedstock availability, consistency and reliability of supply, as well as difficulties in securing a viable tariff for electricity produced. There are also often cheaper competing alternatives to deliver the same energy service, an issue that is becoming more relevant as solar and wind power costs continue to come down rapidly. Combining bioenergy and other renewables may become one of the best alternatives.

Tanzania: KPMG

KPMG staff in Tanzania have been part of the fund management team for the AECF REACT project described above. REACT has supported approximately 15 energy businesses in Tanzania, including Husk Power Systems, Silafrica (for a collaborative venture with Simtank to develop plastic tank and flexi-bag biogas solutions) and a partnership of TaTEDO and CAMARTEC to install domestic biogas systems. Under a separate agribusiness window, AECF supports baseline studies, verification and monitoring and evaluation work. With the transition of REACT management to AECF Ltd., KPMG becomes a less relevant actor in the bioenergy sector.

Tanzania: Space Engineering

This small company was set up by faculty and a graduate from the University of Dar es Salaam and in 2015 won a grant of USD 100,000 from Power Africa (USA) to develop a hybrid solar/gasification mini-grid in Mbozi District, Mbeya Region. The system has reportedly been running since January 2016 and comprises 10 kW_e of solar power alongside a 30 kW_e gasifier from the Indian company Ankur Scientific. 592 connections have been made to households (with an average load of 40 W) and to hulling and milling machines. The installation is interesting for its choice of technology, having opted for equipment from Ankur rather than Husk Power, despite the latter having company representation in Tanzania.

Space Engineering's Technical Director spent a year on a gasifier study exchange to India and is well versed in the benefits and limitations of different equipment options. He chose not to use Husk Power downdraft gasifiers because they are reportedly uninsulated and lack provision for controlling incoming air to the reactor, which (he believes) prevents them from moving above pyrolysis temperatures to achieve proper gasification. They reportedly operate in the 500-550^{o}C range, resulting in excessive production of char and tar. Indeed, this was the observation of the study team when visiting the Husk Power installation at Ssekanyonyi in Uganda.

Space Engineering chose an Ankur system because it has an insulated reactor and allows the incoming air to be regulated to suit different feedstocks and combustion stages. In the Mbeya installation the air regulation has been optimised for both maize cobs and rice husk (depending on the season). Ankur also provides a control panel with basic sensors and gauges to monitor gas pressures and temperatures within the gasifier and gas cleaning system. The aim is to get tar content down to less than 50 mg per m^3 of syngas before feeding to a repurposed Mahindra diesel engine. 1 kg of maize cobs can reportedly produce 1 kWh. Rice husks are less productive due to high silica content.

Space Engineering operates the mini-grid as a commercial concern and charges consumers TZS 280/kWh (12.5 US cents) using pre-paid meters.

The company is impressive for pioneering the 'build, own and operate' business model for gasification in a mini-grid, and for apparently establishing and sustaining its business for 18 months with almost 600 customers. The company also has a good understanding of gasifier technology and its close links to the University of Dar es Salaam give access to manufacturing facilities and R&D support. The commercial proposition in Mbeya nevertheless looks marginal, given that total revenue from the scheme might only be USD 740 per month or USD 8,900 per year[14], which may not be sufficient to manage, operate and maintain the entire system. The power demands of rural households alone may be insufficient to finance systems such as this, requiring a business model based on a more substantial anchor load.

South Africa: Selectra

Selectra is a South African company that began trading in 2006 as 'Biogas Power' and marketed 30 m^3 flexi-bag biogas digesters. These were typically batch-fed with chicken waste and powered dual-fuel generators up to 50 kW_e. Iron filings were used to remove H_2S and a slag lime bath to reduce CO_2. 10-15 bags could be laid next to each other so the system was effectively modular and scaleable. The business model did not prove sustainable, however, as the technology was sufficiently simple (or appeared to be so) that many farmers were able to see an installed facility and copy it for themselves.

The Selectra strategy has instead been to identify more complex European technologies and transfer them to Africa under licence. It has, for example, adopted a containerised anaerobic wastewater treatment concept from a Slovenian company that it is now being installed to handle waste from the Johannesburg City Parks and Zoo. The system operates in the thermophyllic range (55^oC) to achieve short retention times and biogas production of 20 m^3/day. In practice, the sensitivity of the process is steering Selectra to modify the process to operate at mesophyllic temperatures over 12-20 days, making it more robust and easier to operate, with the drawback that daily gas production will fall to 5m^3. The gas is used to generate power while the heat from engine cooling is used only to heat the digester.

Selectra also imported a European 'dairy power box' containerised biogas system that employed both mechanical and pressure cellulosis, though this has yet to take off commercially.

Selectra believes that the main biogas opportunity in South Africa lies in fuel replacement, as grid electricity is so cheap that the country offers no viable market for grid feed-in. Users relying on power generated on site with fossil fuels can

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[14] Assuming 592 households using 40 W for 5 hours per day @ TZS 280/unit, plus one dehulling machine and one mill using 14.5kW_e each for 2 hours per day @ TZS 380/unit, with an exchange rate of TZS 2,237 per USD.

meanwhile offer higher prices, with mines paying as much as ZAR 3-4 (24-31 US cents) per kWh. Selectra has installed a Lipp (German) biogas system at a gold mine run by Harmony Gold that uses a spiral-fold digester design that was quickly deployed on site. The power from the 1 MW_e /3 MW_{th} plant is sold to the factory while the gas partly replaces liquid fuel used in the mine's metallurgical plant and the digestate supports crops on degraded former mining land. There may be additional opportunities for the gas to be used for air cooling in underground mine shafts.

Selectra sees various research opportunities around pre-treatment of feedstocks, especially the woody bedding used in broiler houses, and also in developing technology to remove suspended solids from chicken waste to give a clear liquid with dissolved sugars that would make a biogas feedstock with higher productivity.

South Africa: EnergiDrop

EnergiDrop provides advisory services and equipment to a variety of energy project developers working in AD and gasification. It concurs with the Tanzanian expert (Space Engineering) that Ankur Scientific gasifiers are well conceived units that are well built with good attention to detail.

The company sees the main constraint to further development of bioenergy opportunities in Africa being insecurity of feedstock supply, a limitation raised by several other informants. Commercial viability is inevitably another constraint, especially given low household energy demand in much of Africa. EnergiDrop believes in an 'ABC' consumer model: Anchor-Business-Customer. In other words there should be a significant anchor load to guarantee basic demand (and cashflow) before hooking up smaller business and domestic consumers. This is an understanding only now coming to project developers that were visited in East Africa, several of whom have built mini-grids that are fully reliant on rural domestic customers and which lack sufficient baseload to reach a critical mass of demand and revenue.

In common with Selectra, EnergiDrop believes there are technical research needs in the pre-treatment of feedstocks for biogas systems. In gasification it sees research opportunities in developing reactor designs that can achieve the required temperatures at lower cost, and in effective ways of cleaning up syngas.

South Africa: Anaergia

Anaergia is the global brand name for the former German firm UTS Biogastechnik, which was bought by Anaergia's founder (Andrew Benedek) in 2007. Anaergia has been operating in South Africa since 2014 with the aim of developing opportunities not only to supply UTS biogas technology and management services to new AD projects, but also to introduce other waste processing technologies owned by Benedek's portfolio of companies.

Anaergia's first notable success was to turn around the struggling Bio2Watt AD system at Bronkhorstspruit (near Pretoria) which was performing well below its rated capacity of 4.7 MW_e. Anaergia fitted a double membrane, expanded the gas cooling system and introduced other technical and managerial changes to elevate gas output and engine performance. Anaergia is also the main technology provider to an ambitious new Waste-to-Energy project in Cape Town led by New Horizons, in which it is supplying waste sorting machinery as well as an AD installation to process the organic fraction of the municipal solid waste that is pressed out using proprietary extruder technology from DB Technologies, another Benedek-owned company.

Anaergia's strategy is to operate as an Engineering, Procurement and Construction(EPC) contractor rather than an equity investor in the projects where it works. It sees commercial AD potential in Africa in the 300-800 kW_e output range, though this could also be a reflection of the optimal investment range for the German AD systems that it promotes.

The company believes that the main barriers to AD adoption in Africa are commercial rather than technical. The reluctance of companies to commit to long-term (e.g. 15 year) off-take agreements is a major constraint, so bankable feasibility studies are one important requirement where DFID could potentially make a difference. Areas in need of technical research include ways to address seasonality challenges of many feedstocks, such as turning them into silage for off-season use. More specifically at the Cape Town waste processing facility, Anaergia wants to explore the potential for using the combustible components of the municipal solid waste that are known technically as Refuse-Derived Fuel (RDF). The RDF dry matter fraction could be pyrolised to produce oil and this could be fed to the AD plant that has already been built.

Anaergia is actively exploring AD opportunities outside South Africa, including supplying the upgrade package for the biogas system at Kilifi Plantations in Kenya (see Case Study). It is also looking at the potential to retrofit its proprietary 'Omnivore' anaerobic digester package to double the biogas production of existing installations by co-digesting local organic wastes, typically increasing the digester solids from 2% to between 6 and 8%.

The company is committed to international quality standards and provides performance guarantees at all its installations, and is therefore understandably reluctant to modify the specifications of the European equipment to achieve cost savings at the expense of performance. It is interesting to compare this philosophy with that of Olivado (Kenya) and the Indian gasifier companies, which have taken the different approach of simplifying international technologies, cutting costs and sacrificing performance for the sake of price reduction and operational simplicity.

Ghana: Kwame Nkrumah University of Science and Technology (KNUST)

KNUST is Ghana's leading technical university and has a long history of technical research in the energy sector. Academic staff are officially available for external assignments via the Technology Consultancy Centre, though there have reportedly been challenges getting them to channel work in this way and many opt to work on a freelance basis or via other university institutions.

KNUST's Industrial Ceramic Unit was set up around 20 years ago and has been involved in research into materials for fuel-efficient cookstoves for domestic and institutional use, and even built a low-cost ferro-cement gasifier that is used as a teaching aid. KNUST was part of the advisory team for the ongoing US-funded gasification project at Papasi in Ofinso North District, and has knowledge of a second gasifier from the same supplier that has recently been installed in a school near Tamale with sponsorship from a private UK Trust. While KNUST is optimistic about the technical prospects for gasification in Ghana, it was agreed that commercial sustainability has been a great challenge. The head of the Industrial Ceramic Unit believes that people do not want to have any responsibility for managing rural power systems, but are quite willing to pay for electricity if it is delivered to them reliably. This questions the model used at many rural mini-grids, where local communities are very much expected to take a managerial role.

A third gasifier project was reported at Techiman with IFAD support via SNV. A 120 kW_e Ankur Scientific unit is to be installed and fuelled with cassava peels. The required input is 240 kg per hour, however (2 kg/kWh) and it is not at all clear where such a large volume of feedstock can be procured.

In summary, KNUST offers a useful location for technical experimentation and can avail students and faculty for short-to-medium term research assignments.

Germany: German Biogas Association and Snow Leopard GmbH

The meeting aimed to discuss barriers and opportunities for biogas replication in Africa with employees of the German Biogas Association and a project developer (Snow Leaopard) engaged in commercial activities in Africa, in order to cross-check learnings from the Case Studies with experienced practitioners in Europe's largest biogas market. The German Biogas Association has two employees, one financed by the German Ministry for International Cooperation, directly supporting biogas development in developing countries, including in Africa. They are (or have been) actively engaged in projects in Kenya, Ghana, South Africa and Uganda. Snow Leopard provided some of the biogas technology for the Tropical Power plant in Naivasha, Kenya.

Key barriers mentioned by the participants were: high capital cost of European equipment, poor quality of low-cost mixers due to problems with bearings, difficulty

in accessing finance during the 5 year development phase to achieve bankable projects, lack of biogas laboratories (specifically in Kenya) and missing know-how on biogas among engineers and technically trained people. Further research was not considered the most efficient way to overcome barriers for replication of biogas in Africa by the participants, implying a need to be highly strategic and sensitive in the way any new DFID research funds are directed. It was also made clear that the priority regions for European biogas developers for export of their technology are Asia and Latin America, with Africa low on the priority list.

United Kingdom: World Biogas Expo, Birmingham

The World Biogas Expo organised by the World Biogas Association is one of the largest industrial fairs on biogas globally and the key biogas event in the UK, with attended by a wide variety of technology providers from engine manufacturers, to mixer and pump companies to biogas project developers, some with activities in Africa. The event was a good opportunity to discuss barriers and opportunities for replication in Africa and reflect on learnings from the Case Studies with experienced practitioners. Discussion with two engine providers, Edina and Shenton Group, provided insight on technical options to protect alternators from unstable grids and whether a research opportunity exists. A discussion with a Sales Manager of small steam turbines from Siemens provided valuable input to the research on viability of steam turbines <1 MW_e, while Schaumann Bioenergy provided input on research opportunities on co-substrates and biogas yield optimisation in Africa. The commercial viability and technical barriers of lagoon digesters was discussed with Dutch technology provider Wiefferink, while opportunities for pre-treatment of lignocellulosic feedstocks were discussed with Dorset-based Farmergy, who offer a cavitator technology for pre-treating lignocellulosic feedstocks such as straw.

PlanET, a German biogas project developer with activities in both East and West Africa, and Biogaskontor Koeberle, a German technology provider whose equipment was installed in several biogas plants visited during the Case Study work, provided some further views on barriers and opportunities. Raising financed was mentioned as a key barrier with several facets: technology providers or project developers are expected to bring finance into the project (which they often cannot), an impression among investors that biogas is too complex, the paradoxical ease with which USD 100 M might be raised versus the difficulty in raising USD 4 M for a biogas plant, and top-up interest rates that are sometimes applied by African banks who operate loan funds, even if they are using low-risk resources from donor governments. Other barriers mentioned were high import taxes for spare parts and procurement of an insufficient stock of spares at the project outset by local operators.

Annex C Case Study Reports: Anaerobic Digestion

The following Case Studies are included in this Annex:

Case Study AD1: Thecogas Anaerobic Digestion Plant, SOGAS Abattoir, Dakar, Senegal

Technology	Anaerobic digestion with power and heat generation
Project developer	Thecogas Senegal
Location	SOGAS Abattoir, Dakar
Type of digester	Lagoon digester
Year of commissioning	2013
Primary feedstocks	Cattle stomach contents and abattoir wastewater/blood
Engine size	100 kW_e / 150 kW_{th}
Contact person	Dr. Lamine Ndiaye, Managing Director
Email	*Contact authors if required*
Tel.	
Visit conducted by	Ralph Ripken, E4tech
Date of visit	21st June 2017

Project details

The Thecogas Senegal anaerobic digestion plant is located at the abattoir owned by the *Société de gestion des abattoirs du Sénégal* (SOGAS) on the south side of the capital city Dakar, about 10 km east of the airport. This is the largest abattoir in Senegal, slaughtering about 200 cows and 1,300 sheep and goats daily, and creating 200 t of waste in the process. The abattoir's liquid waste is released directly into the sea while the solid waste is stored on site or transported to a nearby landfill, with associated costs, health risks and environmental pollution. The plant was commissioned in July 2013 at a cost of EUR 750,000 (USD 990,000), funded jointly by Thecogas Senegal (40%) and a grant from the Dutch government (60%). Thecogas is a joint-venture of Thecogas BV Netherlands (35%), and Compagnie de l'Eau, de l'Energie et de l'Environnement du Sénégal (C3E) (65%). The aim of the pilot project is to demonstrate how abattoir waste could be treated to both reduce environmental impacts and generate electricity to offset grid consumption.

The bio-digestion process begins by combining animal cud and stomach contents with blood and waste water from the abattoir in a 45 m^3 concrete mixing pond. The liquid waste stream is piped directly to the pond while the solid waste is brought there by truck. For part of 2015, manure was also added. A 15 kW_e pump mixes the solid and liquid substrate streams in the pond.

The substrate feeding volume changed from 24 m^3/day in 2014, to 29 m^3/day in the first half of 2015 to 16 m^3/day from July 2015 onwards, against a design ceiling of 45 m^3. The fluctuating volumes reflect changes in feedstock composition. During 2014 and the first half of 2015, feedstock averaged 4 t/day of stomach/cud content and 20 m^3/day of waste water from the abattoir. During the first half of 2015, 15-25 kg/day of manure was also being added. Due to high nitrogen content, the liquid input was reduced to 10-12 m^3/day from mid-2015. Since then, daily input has been maintained at around 3-4 t of solid matter and 10-12 m^3 of liquid. The mixing pump can be used in a different mode to pump substrate into the digester for 30 minutes per day, six days per week.

The digester is a lagoon-type design with a substrate capacity of 2,500 m^3 and a gas storage capacity of 1,500 m^3. It is installed over a rectangular earth basin, lined with a plastic sheet, and connected by ropes every 3 m to metal springs to allow for gas expansion. The bag was manufactured by a Dutch company. The digester contains two horizontal mixers of 15 kW_e which are located in two 2x2m entrances for ease of access for repair (see picture below). Excess biogas can be flared via a pressure release valve. At the time of the visit, the digester bag was only partially filled, being buffeted by the wind and possibly leaking digestate at the edges. The sub-optimal biogas production was attributed to a breakdown of the engine that had been intended to generate electricity (see below), and as a consequence lower organic loading rates.

The mainly liquid digestate is pumped twice per week back into the mixing tank, while it is empty, and from there pumped to a transporter tank. Some digestate always remains in the digester and is not taken out. The maximum working temperature of the digester was reported to be 40°C, though was only 27°C during the visit, presumably due to non-operation of a system of internal heating pipes that was designed to circulate hot water at 50-70°C from the engine exhaust. The pH of the digester is not measured, which represents a risk in rapidly identifying changing digestate conditions. The standard substrate retention time is 30 to 40 days. Due to the fibrous structure of the cow stomach contents and high lignin levels, however, around 40-50% of the substrate is reportedly not digested within the standard retention time.

The biogas is captured in the expandable bag and channelled via a large pipe to a desulphurisation unit, via a condensation trap and centrifuge to remove moisture. Daily gas production was 800-900 m^3 when the engine was operating but is currently only 100 m^3. Gas quality is monitored twice per day and CH_4 content is reportedly 60%. H_2S content can reached 1,000 ppm and the aim is to keep this below 200 ppm. In addition to the desulphurisation with two iron granulate filters to decrease the

quantity of H_2S, air is injected into the digester in a controlled manner via two pumps.

From the desulphurisation unit the biogas is pumped to a 100 kW_e/150 kW_{th} CHP engine located in an adjacent building. It has an electrical efficiency of 38%, a thermal efficiency of 54% and a total efficiency of 92%. The generator is from Leroy Somer. 1.6m^3 of feedstock was reported to produce 1 m^3 of biogas, which in turn can produce 2 kWh of electricity. The biogas plant consumes around 15 kW_e and the balance of 85 kW_e can be sold to the abattoir. The engine is currently not operating, however, due apparently to the quality of the engine itself and the quality of water in the abattoir. The exact problem could not be identified during the visit.

If the engine is running then exhaust heat (at 400°C) as well as cooling heat is transferred via a heat exchanger to heat water to 50 and 70°C for use in the abattoir and for heating the digester.

The abattoir spends XOF 100 M (USD 174,000) per annum for 680 MWh_e of electricity. The cooling room is its largest single consumer (90 kW_e). A 20 year electricity purchase agreement was drawn up for buying power from the biogas plant at XOF 101 (17.6 US cents) per kWh, lower than the mains electricity tariff (daytime XOF 120, evening XOF 140/ [21 or 24 US cents]). If the engine operated at a capacity factor of 91%, then the biogas plant could supply the full 680 MWh p.a., potentially saving the abattoir XOF 16.3 M (~USD 28,400) and generating XOF 69 M (USD 119,400) for the biogas plant.

In practice, total supply from the biogas plant to the abattoir was only 117 MWh in 2014 and 108 MWh in 2015, which covered only 16-17% of the abattoir's requirements. The engine operated for 1,628 hours in 2014 and 1,724 hours in 2015, implying average output of only 66-67 kW_e (78% of potential export capacity) and engine operating time of only 4.5 to 5 hrs/day (versus a target of 10 hrs/day).

The electricity saved the abattoir an estimated XOF 2.5 M (~USD 5,000) per annum and generated XOF 10-11 M (USD 18-20,500) for the biogas plant, significantly less than reliable operation would have allowed.

The plant was also intended to produce solid fertilizer, for which a market is being developed. Some of the fertilizer is reportedly sold to the local government in liquid form at XOF 50 (9 US cents) per litre, but there are no sales of solid fertilizer.

The capital cost of the biogas plant was EUR 750,000 (USD 990,000), including installation. This equates to around USD 9,900 per installed kW_e. Annual projected income from electricity sales was equivalent to USD 18-20,500 in 2014/15, giving a payback period of about 50 years and rendering the project commercially unviable at a low level of electricity production. Valorisation of the heat and fertilizer are essential to achieve viability.

An extension of the plant is planned for 2018 with 50% financing from the French Development Agency and the balance to be raised elsewhere. EUR 2 M (USD 2.2 M) (or USD 8,000/kW$_e$) is required for two 2,500 m^3 concrete digesters, a separate 3,000 m^3 gas storage bag and an additional 250 kW$_e$ engine.

The plant is overseen by C3E Managing Director (Lamine Ndiaye) and is operated by an electro-mechanical engineer who received a three months biogas training in the Netherlands, and is supported by three secondary-educated technical operators (with specific technical training) and six specialized workers. It was unclear whether any of the operators had previous biogas experience. A maintenance contract is in place with Thecogas Netherlands who visit the project every six months and in case of emergency. It was reported that spare parts are generally available in Senegal. The technicians look after the digester and search for potential leaks on a daily basis. The engine air filter, fuel filter and oil cartridge are replaced every 2,500 hours.

Photos

Solid feedstock feeding into the pre-mixing tank

Solid feedstock

Waste water stream (L) and mixing pump (R)

Electrical switchgear


Air injection units


Lagoon digester w/ rectangular entrance to mixer 1


Heating pipes entering the digester


Plastic pipes between digester and mixing tank


Engine container (heat exchanger on top) and desulphurisation unit


Desulphurisation unit


CHP engine


Heat exchanger

Barriers and opportunities for replication

The biogas plant at the SOGAS abattoir in Dakar demonstrates the technical feasibility of anaerobic lagoon digestion using abattoir waste to partly replace grid electricity. Even though the use of the feedstock can help the abattoir with a disposal problem and has the potential to offer savings of around USD 28,400 p.a. on electricity costs should the engine operate at full capacity, it is questionable whether the abattoir has a genuine vested interest in the successful operation of the biogas plant. This is especially so given that a potential fine of XOF 100 M (USD 175,000) for uncontrolled waste disposal is not enforced. The project currently only valorises the electricity output and operates below 20% capacity, while income from fertilizer sales is negligible and heat is not sold. The plant fulfils its purpose as demonstration plant, but is not commercially viable operation.

Non-technical barriers relate to an absence of locally available after-sales service or spare parts in Senegal to fix and repair complicated issues quickly. The maintenance contract with Thecogas, based in the Netherlands, is not proving sufficient - as shown by the current non-operation of the engine. Other non-technical barriers reported by the project owner are the lack of awareness and knowledge of the benefits of biogas among local and national politicians, and a shortage of well-trained local technicians. To reach commercial viability in any potential replication project, all three income streams (electricity, heat and fertilizer) would need to be valorised and the feedstock provider should have a vested commercial interest in the success of the project.

Technical barriers in the project have included the high nitrogen content in the blood, limited availability of solid feedstock to balance the quantity of waste water and the difficulty for full digestion of the fibrous content from cow stomachs. A pre-treatment technology for lignocellulosic feedstock (such as a cavitator) could potentially overcome this problem and increase biogas yields. The low overall electricity production in 2014 and 2015 (below 20% of design potential) demonstrates a technical problem in the biogas system, though it could not be determined whether this was due to limited feedstock supply, biological problems in the digester (pH, temperature or H_2S content) or operational problems with the engine. Possible leakage in the lagoon due to abrasion or salt content of the liquid waste feedstock impacting joints represent further technical barriers. Prior to further project extension it would be recommendable to overcome these barriers to ensure long-term project success.

Although not exactly ‘pro-poor’, the plant, similar to many others, has brought local benefits from waste disposal, job creation, technical skills development, grid electricity replacement and limited organic fertilizer production. Research on the

optimisation of the feedstock composition to optimise yields, potentially using a pre-treatment technology for lignocellulosic feedstock and automation of the feedstock supply to the pre-mixing tank and then digesters could avoid the irregularity of the current feedstock supply. Further opportunities to achieve replication lie in developing a local training centre for biogas to guarantee sufficiently well trained and available personnel for biogas plant operation.

Acknowledgements

I am indebted to Dr. Lamine Ndiaye for facilitating a visit of Thecogas's biogas plant and for giving up several hours of his day to give me an interesting and informative tour. We appreciate the company's impressive commitment to biogas development in Senegal, and it was very kind of its staff to share their best practices and lessons learnt.

This report has been fact-checked by Thecogas Senegal, but the opinions contained herein are solely those of the DFID-contracted consultant.

Ralph Ripken
26th July 2017

Case Study AD2: HPW Fresh and Dry Anaerobic Digestion Plant, Adeiso, Eastern Region, Ghana

Technology	Anaerobic digestion with heat generation
Project developer	HPW Fresh & Dry
Location	Adeiso, Ghana
Type of digester	Two stage digester
Year of commissioning	2011
Primary feedstocks	Mango, pineapple, papaya & coconut waste, palm kernel cake, poultry manure
Engine size	400 kW_{th} (rated at 650kW_{th} for natural gas; decommissioned engine was rated at 120 kVA / 96 kW_e)
Contact persons	Maik Blaser, Managing Director Bright Keme, Technical Manager Shadrack Ofori, Environmental Officer
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	26th June 2017

Project details

The HPW Fresh & Dry anaerobic digestion plant is located at the company's fruit drying factory near Adeiso in Ghana's Eastern Region, 50 km north-west of Accra. This is the most modern facility of its type in West Africa, employing 800 staff, processing an average of 40 t of fruit per day and exporting around 1,700 t of dried fruit per year[15]. The original factory was built in 2011 at a cost of CHF 3.5 M (USD 3.85 M) and was expanded in 2016 with the construction of a second facility on the same site costing a further USD 3 M.

The biogas plant was built concurrently with the factory in 2011 to produce electricity and heat for the fruit processing and drying operation. The initial investment was

[15] Deuber, K. & Siegert, D (2014) *Ananas, getrocknet: Wie ein Schweizer Ghanas Früchte exportiert.* http://www.srf.ch/news/wirtschaft/ananas-getrocknet-wie-ein-schweizer-ghanas-fruechte-exportiert

financed by HPW and supported by a EUR 900,000 (USD 990,000) grant from the Dutch Ministry of Foreign Affairs, given the punitive interest rates reportedly payable on bank loans[15]. It was designed and constructed by a Swiss technician (Markus Ottinger) using components from Europe and biogas storage bags from China[16].

The plant was designed to provide HPW with the following outputs:

1. Heat for the fruit drying operation, to partly replace diesel consumption;
2. Power for the factory's electricity needs, to complement grid and solar power;
3. Slurry to substitute for synthetic fertilizer on the company's pineapple fields; and
4. Reduced costs of waste disposal for the fruit residues.

The process begins with the feeding of fruit waste from the factory via a floor-level grate into a macerator, where it is mixed with water and recirculated slurry to assist gravity flow down to a mixing tank. Non-fruit feedstock such as palm kernel cake and poultry manure is also added to this tank. A 7.5 kW_e pump recirculates some of the liquid back up to the feed intake to minimise fresh water addition.

Feedstock composition varies seasonally, with mango dominant from late April to early August and during December and January, and pineapple (80%) during other seasons. Papaya and coconut waste are added during both seasons. 20 m^3 (16 t) of fruit waste is mixed with 5 m^3 of re-circulated effluent per day to give maximum daily feeding of 25 m^3. In 2012, the average daily feeding rate was 18.2 m^3 [17]. Depending on FOS/TAC[18] and pH measurements, the plant operator decides whether to feed over 24 hours or over 10 hours.

Feedstock composition	Dry matter content [%]	Organic dry matter content [% of DM]	Organic loading rate [kg of ODM per m^3 per day]
Mango season	16%	90%	2.8
Outside mango season	13%	90%	2.2
Outside mango season in 2012	-	-	2.6[17]

To allow for greater feedstock flexibility, a 12 m^3 concrete hydrolysis tank was added after the mixing tank in 2015. At the time of the visit this was non-functional due to a

[16] Component manufacturers: Stirrer: Odermatt; Pump: Vogelsang; X-Ripper: Vogelsang; Engine: Camda
[17] Grim J. & Johansson M. (2012) *Evaluation of a biogas plant in Adeiso, Ghana.* Project report for Masters Programme in Energy Systems Engineering. SLU, Swedish University of Agricultural Sciences. Uppsala.
[18] FOS/TAC represents the ratio of volatile organic acids to alkaline buffer capacity and indicates the acidification risk of a biogas plant.

broken mixer. Acidity had corroded a seal in the mixer and liquid entered the motor. Due to a shipping mix-up it took six months for a replacement part to arrive.

The feedstock is pumped from the hydrolysis tank by an 7.5 kW_e pump to two semi-sunken concrete digester tanks of 450 m^3 each. These were originally designed to operate in series in a two stage process, but the inter-connecting pipe became blocked with viscous slurry, so the tanks are now operated in parallel in a single stage.

Each digester has an 11 kW_e horizontal mixer. Liquid slurry is periodically pumped out to a tanker-trailer for use on the company's pineapple farms, while solid slurry is manually shovelled out of an overflow as gas pressure pushes it up. This is composted for use in the company's seedling nursery. A system of heating pipes inside both digesters circulates hot water from the factory's fruit chillers, although this may not be fully effective as the internal temperature on the day of the visit was only 28.9°C, somewhat below the 34-38°C target range and not ideal for optimising biogas yields.

The pH of the first digester was 6.9 but the contents of the second had acidified and it was being emptied before being restarted from scratch. The reasons for the acidification were not fully understood, but it was assumed by HPW that it could have resulted from a rapid change in feedstock composition, combined with overfeeding.

The hydraulic retention time in the digester is 30 days. The biogas is captured at the top and channelled to three PVC storage balloons of 90m^3 each[19]. The gas meter has broken, but estimated production is 600 m^3/day. Gas quality is monitored twice daily and measurements on the morning of the visit revealed 52.7% CH_4, 39% CO_2, 0.9% O_2 and 150 ppm H_2S. Air injection into the digester is intended to reduce the H_2S level. A desulphurisation unit is also being used (iodated activated charcoal). The H_2S concentration is below the maximum recommended level of 200 ppm (footnote 17).

The gas from the storage bags is piped to a dual-fuel 400 kW_{th} biogas-diesel boiler located at the first factory (with thermal efficiency of 80%). Moisture in the gas is condensed inside this pipe. The boiler is positioned alongside a hot water tank supplied by roof-mounted solar-thermal units (rated at 200 kW_{th}) and a diesel-only boiler (rated at 600 kW_{th}), permitting a blended mix of heat from biogas, solar or diesel to be brought on stream according to the factory's fluctuating demand. Combined with the diesel back-up, CHP total thermal output is 3,200 kW_{th}, sufficiently above the installed capacity of the heat exchangers in the dryers of 1,950

[19] One back-up balloon was available in case of breakage.

kW$_{th}$. The dryers, however, never all operate at the same time even during periods of peak demand. The dual-fuel biogas-diesel boiler uses 1,000 l of diesel per week on average, based on operation for 12 hours per day .The warm water at 83°C from the three systems is circulated through heat exchangers in the ceiling of the fruit drying rooms, bringing the dryers up to 65°C.

The solar, dual-fuel and diesel boiler provide the heat for the first factory, while a 1.6 MW$_{th}$ biomass boiler using coconut residues, briquettes and cashew shells produces the drying heat for the second factory. Total daily energy demand of the two factories is 42 MW$_{th}$ and 6 MW$_{e}$.

Electricity for the two units comes from a combination of the national grid, solar PV units with an installed capacity of 109 kW$_{peak}$ and two 650 kVA diesel CHP back-up generators which could provide another 400 kW$_{th}$. A biogas CHP engine from Camda Generator Work Co. (China) rated at 96 kW$_{e}$ was decommissioned in 2014 due to poor performance and a reported electrical efficiency of only 8%. All the biogas is therefore now used for the generation of heat, rather than both heat and power as had originally been intended.

The capital cost of the biogas plant was USD 450,000, including installation. This equates to around USD 1,125 per installed kW$_{th}$. Operational costs are USD 0.01/kWh$_{th}$. The biogas replaced 120,000 l of diesel in 2016 worth USD 96,000 and 4,500 m^3 of fertilizer for the pineapple worth USD 12,000. If the plant is operating continuously, the total annual savings of diesel and fertilizer would therefore be USD 108,000 and this would give a payback period of less than 5 years.

The plant is overseen by HPW's Technical Manager and is operated by the Environmental Manager, a Ghanaian trained Renewable Energy Engineer without prior experience in biogas generation. Two further technicians are responsible for daily operation. A total of 10 staff work at the plant during one shift. To avoid potential down-time, the company tries to keep fast-moving spares for the boiler and pumps in store on site. All other parts, including mixers, however, needed to be imported.

Photos

Feedstock feeding point with under-floor shredder

Mixing tank

Hydrolysis tank

Daily gas and digestate measurements

View of the two concrete digesters

Digester 1 with overflow shaft

Digester 1 with inlet for heating pipes

View through bulls eye of Digester 1

Empty (acidified) digester with internal heating pipes

Solid slurry outside Digester 1

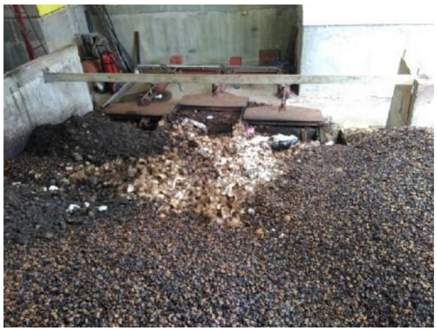

Biogas storage bags


Dual-fuel diesel-biogas boiler


Diesel boiler with exhaust and water storage tanks


Desulphirsation unit


1,600 kWth biomass boiler in factory two


Cashew nut shell feedstock for biomass boiler

Barriers and opportunities for replication

The biogas plant at HPW in Ghana is a successful demonstration of the potential of anaerobic digestion to use fruit waste as a feedstock and to supplement a diesel and solar-powered heating system. The operation shows that it is possible to build a relatively simple biogas system in Africa based on concrete digesters and PVC storage bags. It is notable that the feedstock and all outputs are fully controlled by HPW and the company has a vested interest in the success of the operation because it benefits from cost-savings on diesel and fertilizer that potentially exceed USD

100,000 per year. It is unclear, however, whether the biogas plant is commercially viable or how much biogas has been produced since the start of the operation in 2011.

Non-technical barriers relate mainly to the manual nature of the feeding process, which can cause irregularity in feedstock supply and potentially affect the physical and chemical properties of the digestate. It is likely that the acidification of the second digester was caused by irregular feeding and rapid change in the composition of the feedstock. It is apparent that successful operation requires significant experience in operating biogas plants and knowledge of key parameters such as retention time, to ensure consistent biogas production and adjustment to the feedstock composition to avoid acidification.

Technical barriers in the project have included the low durability of the mixer in the hydrolysis tank, an undersized inter-connector pipe between the digester tanks (leading to blockage) and leakages in the PVC biogas storage bags reducing overall efficiency. The decommissioning of the CHP biogas engine could have probably be avoided if a higher quality engine had been acquired. The temperature in the operational digester was below the recommended mesophilic temperature range for optimal biogas production, perhaps indicating non-operation of the heating pipes.

Although not exactly 'pro-poor', the plant has brought local benefits from waste disposal, job creation, technical skills development, diesel replacement, emissions reduction and organic fertilizer production. Automation of the feedstock supply to the hydrolysis tank and digesters could potentially avoid the irregularity of the current feedstock supply. Further opportunities for research lie in the optimisation of the feedstock composition and operational conditions of the digester to optimise biogas yield.

Acknowledgements

We are indebted to Maik Blaser for facilitating a visit of HPW's biogas plant and to Shadrack Ofori for giving up several hours of his day to give us an interesting and informative tour. We appreciate the company's impressive commitment to biogas development in Ghana, and it was very kind of its staff to share their best practices and lessons learnt.

This report has been fact-checked by HPW Fresh & Dry, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
24th July 2017

Case Study AD3: Safi Sana International Biogas Plant, Ashaiman, Greater Accra, Ghana

Technology	Anaerobic digestion + power generation
Project developer	Safi Sana International, financed by
Location	Ashaiman, Greater Accra, Ghana
Type of digester	Continual flow single stage industrial digester
Year of commissioning	2016
Primary feedstocks	Market organic waste, abattoir waste, latrine waste
Engine size	96 kW_e (120 kVA)
Contact person	Raymond Okrofu, Country Manager, Safi Sana Ghana Ltd.
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	24th June 2017

Project details

The Waste to Energy and Organic Fertilizer Facility at Ashaiman is a project of Safi Sana Ghana Ltd., the local branch of the NGO Safi Sana International. The project was funded with around €2 M from the African Development Bank, the African Water Facility and the Ghana Netherlands Wash Programme, and was commissioned in August 2016 at a 2 ha site about 20 km east of central Accra.

The aim was to convert three streams of bio-wastes to energy and fertilizer, solving a waste disposal problem while generating revenue from sales of power and digestate. The project was conceived as a pilot site to demonstrate the technology and business model.

It is a large and ambitious installation built with equipment from credible European suppliers such as Nujhuis Industries (Netherlands). The centrepiece is a 2,500 m^3 digester with three internal mixers and an in-built heating system that uses hot air blown through the engine cooler to heat water to keep the digestate temperature between 37 and 39^{o}C. It is the first grid-connected biogas plant in Ghana and only the second in West Africa.

There are three feedstock supply streams. The first is manure and stomach contents of cattle from a local abattoir, comprising part-digested vegetable matter. This is fed directly to a mixing pit where it is combined with the other feedstocks. The second

input is organic waste from traders at nearby Ashaiman market, which Safi Sana collects twice daily using 3-wheeled auto rickshaws. The traders have to pay a daily disposal fee to the municipal government and this cost can avoided if their fruit and vegetable waste is diverted to the biogas plant. This waste is sieved and macerated on site, before entering the mixing pit. The third feedstock is latrine waste from Safi Sana's own community sanitation blocks. This is fed into two liquid pre-pits from which it also flows into the central mixing chamber. The preferred ratio of feedstocks is 8-12 t abattoir waste, 4-6 t organic market waste and 10 t latrine waste (roughly 2:1:2). The combined material is mechanically pumped into the digester. The plant has a theoretical feeding capacity of 25 t/day with a retention time of 90 days, though it was not possible to determine actual feeding rates and the visit was made at a weekend when the workers were not on duty.

The gas is blown into a Scania gas engine rated at 96 kW_e. H_2S is removed using an air pump inside the digester that ensures oxidation of H_2S and sulphate removal and there is no additional (inline) H_2S scrubber. The composition of the gas entering the engine is not known (e.g. H_2S and moisture levels). Air is blown through the engine radiator and the hot air passes through a heat exchanger in which water is heated to 60-80^oC and then circulated to a network of pipes inside the digester to keep it at optimal operating temperature, although the control panel showed it to be at 35^oC, slightly below target. The exhaust heat is not used. Power from the engine is fed directly to the mains grid under a Power Purchase Agreement that sees Safi Sana earning 17.5 US cents/kWh, possibly the most generous Feed-in Tariff in Africa and comparable with subsidised European rates. The Electricity Company of Ghana pays Safi Sana on the basis of net consumption after internal use has been deducted, as recorded by a meter at the edge of the compound.

In theory the system should generate 2.1 MWh of power each day, assuming 22 hour operation. The system control panel shows that total time since commissioning is 7,164 hours (298 days) while the engine has operated for 1,677 hours and generated 130,580 kWh. This represents a capacity factor of 15.5%. Average operating time has therefore been 5.5 hours per day at an output of 78 kW_e, which indicates that the engine operated at 81% of its rated capacity of 96 kW_e. Daily power production has averaged 0.44 MWh, only 20% of the projected 2.1 MWh. There have been 2,664 engine starts in 298 days, suggesting an average of nine starts per day. This is likely to indicate frequent shutdowns due to low gas quantity or quality. Gas pressure at the time of the visit was 0.313 bar.

According to the utility's electricity meter, 10% of the power is used internally for the plant's own pumps, mixers, lighting and office equipment, meaning total power exports of 118 MWh since installation with a value of USD 20,500 (USD 2,050 per

month of operation). Operating expenses are not known but it seems likely they are higher than this.

Additional revenue is derived from sales of dried digestate as fertilizer at GHS 30 (USD 6.90) per 30 kg bag. The solids are separated from the liquids in a series of post-digester settling tanks. The liquid digestate has value as irrigation water and output is potentially 20,000 l/day, though it is not clear if sales have taken place.

Up to 2 t/day of solid matter can theoretically be produced. This material cannot be used directly, however, because it still contains pathogens from the latrine waste feedstock. With a 90 day retention time it is not clear why this is the case. The Safi Sana digestate must be composted under plastic sheets for several months to ensure that it is safe to apply to crops. The organisation has a professional chemist and an on-site laboratory to check this material for safety.

An additional income steam is being developed from the sale of seedlings of high value horticulture plants (such as tomatoes and green peppers) and herbs (such as basil).

Photos

Feeding area for abattoir waste

Liquid pre-mix tanks for latrine waste

Feed conveyor for organic waste

Macerator for organic waste

Mixing pit for three feedstock streams

Digester (at rear) and drying beds

Air pump to oxidise H_2S in digester

Gas engine

Drying bed (one of several)

Composting area and seedling greenhouse

Barriers and opportunities for replication

The Safi Sana plant has the potential to be a commercial success based on Ghana's generous Feed-in Tariff, given that projected income from power sales could exceed USD 300 per day. Avoided waste disposal, heat and digestate would also need to be valorised to deliver a viable projects, however, in order to fully cover costs of depreciation, operation and maintenance. Multiple income streams are key.

Another challenge seems to be securing sufficient feedstock of appropriate quality at a competitive price. While data on actual feedstock quantities was not available, the frequency of engine re-starts, the 'low gas' alarm history and power output 80% below expectations all suggest that gas production is well below target levels. Low engine hours affect the heating function and probably explain the sub-optimal operating temperature. A thick scum on the digestate surface (as viewed through an inspection window) offers further evidence that gas production is impeded.

It is understandably difficult to ensure correct pH and nutrient composition with highly varied feedstocks over which the plant operator has only limited control. Sieves are being used to remove the most obvious contaminants (such as metals, plastics and sanitary materials) before they enter the system, but the make-up of the feedstock must be continually changing and this doubtless makes for challenging management. Market waste is normally not separated at the market, leaving plastic waste in organic fraction. Safi Sana has started a program incentivising market traders to collect organic waste separately.

Using latrine waste as a feedstock is theoretically viable but is proving problematic and necessitates a labour-intensive post-digester composting process, adding costs that would probably be avoidable if latrine waste was not being used.

In conclusion, valorisation of multiple income streams could potentially make for a commercial viable operation, but gas output seems to be well below planning assumptions. The apparent shortage seems to result from insufficient feedstock, over-sized solid components and the wide and unpredictable variety of source materials. Finer chopping and better mixing might partly address this. More gas would mean longer engine operation and better substrate heating, which would have a positive feedback. The hygiene issues with the digestate results from the input of faecal matter and may only be solvable by ceasing input of this feedstock.

Replication should be possible in Ghana given the attractive Feed-in Tariff, but other plants would ideally need to be smaller and sized more appropriately for the *proven* volumes of available feedstock, operating on a worst-case scenario. Both heat and digestate must be valorised to ensure commercial viability. Latrine waste should ideally not be used in a single stage digester. Locating plants right next to the feedstock source is a cost-saving measure that further improves security of supply.

Research could potentially assist in characterising the digestate and developing solutions to increase gas yields. This might need external expertise and retrofit of supplementary equipment, such as surface mixers.

Acknowledgements

We are grateful to Raymond Okrofu of Safi Sana for allowing us to visit the biogas plant as part of a study team with the ECOWAS/GBEP Bioenergy Week that was taking place in Accra in June 2017.

This report has not been fact-checked by Safi Sana Ghana Ltd and the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
29th June 2017

Case Study AD4: Avenam Links International Biogas Plant, McNichols poultry farm, Ogun State, Nigeria

Technology	Anaerobic digestion + power generation
Project developer	Avenam Links International
Location	McNichols poultry farm, Papalanto, Ogun State
Type of digester	2-stage 'red mud' flexi-bag
Year of commissioning	2017
Primary feedstocks	Poultry manure
Engine size	5.5 kW_e (potential for 15 kW_e)
Contact person	Nina Ani, CEO, Avenam Links International
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant
Date of visit	21st June 2017

Project details

Avenam Links International is probably Nigeria's leading indigenous developer of biogas systems, having installed a number of plants using different technologies and feedstocks with both private and public sector partners. A contract was secured in 2016 with the owner of McNichols Consolidated Farm to install a biogas system at the company's poultry operation just east of Papalanto in Ogun State, 70 km north of central Lagos. The project has been fully financed by the owner of the farm, making it unusual for having no element of government or donor funding. The resulting challenge for Avenam has been to balance the owner's desire to manage costs with the need to install a minimum level of equipment to ensure a properly functioning plant. Avenam would like the installation to serve as a demonstration of viability for other poultry farmers, so the company's CEO (Nina Ani) is doing all she can to make the operation a positive demonstration of the technology's potential, despite the customer's limited budget.

The farm houses around 13,000 layers that generate 1,300 kg/day of manure. This is currently dumped, together with feathers, washwater and broken eggs, in an unsightly lagoon immediately below the chicken house. Worms in the lagoon attract wild birds such as egrets, presenting a risk of disease transfer to and from the poultry, according to the farm's resident vet. Polluting leachate from the dumped waste may also be affecting the local groundwater, judging by the poor quality of

water extracted from a borehole recently sunk in the lower part of the farm. The installation of a biogas plant in May 2017 promises to rid the farm of this troublesome waste, whilst also supplying electricity for the farm's water pumps and lights. The site has no grid power connection and currently depends entirely on a generator.

The first stage of the biogas system is a mixing pit where water should be added to the poultry waste at a ratio of 2:1, in order to dilute the ammonia (ammonia stripping technology being beyond the client's budget). Water is in short supply, however, as the borehole yield has been disappointing, so the dilution ratio is below target. Water shortages in fact delayed construction of the plant by three months and are an ongoing constraint.

A submersible pump with a float switch then takes the feedstock from the mixing pit to a two-stage digester comprising two 90 m^3 'red mud' bags (180 m^3 combined capacity) from the Chinese company Teenwin. Residence time should be 40 days and pH is 7.8 to 8.0. From there the gas passes through a filter to reduce H_2S from 2,115 ppm and then a water trap, before entering a 50 m^3 storage bladder. A pump takes it onwards to a dual-fuel 5.5 kW_e Chinese-made generator set. The gas fed to the generator contains around 10% CO_2.

All elements of the installation are above-ground because of seasonal waterlogging, making the flexi-bag digester and gas storage bag an ideal choice.

The feedstock contains 30% dry matter and the gas production rate is 0.25 m^3/day per kg of dry matter. Therefore with 13,000 birds and 1,300 kg of daily input, 97.5 m^3 of gas can be produced per day. At 60% methane content, it was predicted that this could power a 5.5 kW generator for up to 24 hours per day. The plant has been sized for up to 2,000 kg/day of feedstock supply to allow for expansion to 20,000 birds, with a potential gas output of 150 m^3 per day.

The table below shows the estimated gas production and generator operating hours for different feedstock volumes.

No. of birds	Waste (kg/day)	Biogas production (m^3/day)	Methane content @ 60% (m^3/day)	5 kW generator (hrs/day)	15 kW generator (hrs/day)
20,000	2,000	150	90	37.8	12.6
13,000	1,300	97.5	58.5	24.6	8.2
7,000	700	52.5	31.5	13.2	4.4

The farm staff had been running the gen-set for 6 hour daily stints prior to the visit, but this used up all the gas as they were not adding sufficient feedstock. The farm worker delegated to delivering feedstock has been unhappy with his new duties and feeding the mixing pit at well below the required rate. Daily feedstock input averages

only five wheelbarrow loads rather than 1,300 kg, which inevitably results in gas production well below the design targets.

The owner was trying to incentivise the workers to feed the biogas plant by making them pay for generator fuel themselves, hoping this would encourage them to feed the digester sufficiently to produce more biogas. While this was working to some extent, the gas storage tank was empty at the time of the visit - though the situation was improving (and indeed a photo sent later in the week confirmed it had re-filled). A longer term solution is the installation of a 6 inch plastic feeder pipe running from the poultry house down to the biogas unit. This has just been finished and will shortly be commissioned. It should significantly reduce labour demands and increase the feed rate, hopefully bringing the system up to the envisaged operating level.

A further challenge brought about by the tight budget is an accumulation of chicken feathers in the feedstock. These could be chopped before entering the digester if a cutter pump had been incorporated, but the client opted for a standard pump to keep costs down. The feathers may cause the pump to break and there are concerns about scum formation in the digester. A simple pre-sieving system will be fitted to minimise the intrusion of feathers, though this is unlikely to be 100% effective.

Once feeding levels increase and sufficient digestate accumulates, the intention is to dewater it using a mechanical extruder and to sell the solid digestate as fertilizer, while applying the liquid slurry on the owner's farm.

The dewatering equipment is already on site awaiting assembly, but will need a 15 kW_e engine. The farm owner is waiting for gas production to stabilise before making this additional investment. The 15 kW_e engine could be run for over 12 hours per day once the farm expands to 20,000 birds (see table above).

The dry fertilizer can reportedly be sold locally for between NGN 2,500 and 3,500 per 50 kg bag (USD 7.70 to 10.80), whereas a bag of synthetic fertilizer costs NGN 8,000 (USD 24.60). In fact the value of the fertilizer is projected to be equivalent to the value of the fuel savings for running the gen-set. Fertilizer output may be as high as 390 kg per day, based on the dry matter content of the feedstock, giving potential daily income from fertilizer sales of over NGN 20,000 (USD 63).

Total investment to date has been NGN 12 M (USD 37,000) and payback time based on generator fuel savings and fertilizer sales is expected to be 2.5 years. A manager with basic technical education has been recruited to operate the biogas plant, but existing farm workers are expected to perform routine duties such as supplying feedstock and running the generator. Operator training was conducted on-site by Avenam over a few days.

Photos


Waste dumped by poultry houses


Biogas system pre-pit


Digester bags (partly full)


Gas storage bag


Dual fuel gas/petrol generator


Slurry pit

Barriers and opportunities for replication

The Papalanto biogas plant is interesting for its reliance on private financing, meaning that the technology provider has had to make compromises that are not usually necessary in donor-financed projects. This has resulted in a stripped-down installation that represents a more replicable and sustainable business proposition because it is more closely aligned with the spending power of local farmers.

The low budget approach has inevitable drawbacks, however. For example, the omission of a chopper for the feedstock may have repercussions for build-up of surface scum in the digester that will reduce gas production (despite the inclusion of a sieve to block feathers); the lack of shade over the digester and gas storage bag will also probably reduce their working life. But if a small-scale farm system can be

locally designed and built for less than USD 40,000 then it potentially becomes viable for many more farmers than high-tech imported technology.

Some components are still relatively expensive and lower-cost options are required for the following equipment to make biogas plants more affordable in Nigeria:

- Manual or semi-automatic mixer;
- Submersible pump with sharp cutter; and
- Low power solid/liquid separator for the digestate.

If more of the equipment could be locally manufactured, costs could potentially be reduced – as long as quality was maintained.

From an operational perspective it seems that the farm owner did not plan for the additional labour demands of the biogas plant and his existing staff have been unwilling to put in the extra work to operate the system. A lesson has been learned about the need to recruit or reassign staff to take on the new roles. The staff have lacked a sense of ownership as the investment was made independently by the owner without involving them until construction was complete. It was fortunate in this case that the client agreed to the additional cost of a pipe to convey waste from the chicken house to the mixing tank.

Avenam Links offers a three month service guarantee and the CEO has been on site frequently. In practice she will provide much more support than contractually required. It is clear that customers who are unfamiliar with anaerobic digestion require ongoing technical assistance. This costs money, however, and the company cannot continue to provide indefinite free support. Funds to support a longer-term service facility would result in better performing plants and more satisfied customers.

A key barrier to replication is financial. Farmers may find biogas an attractive proposition over, but many would require credit facilities so they could pay for its instalments. Biogas is not seen as a viable lending opportunity for local banks.

Acknowledgements

I am indebted to Nina Ani, the CEO of Avenam Links International, for kindly agreeing to take me to the biogas plant, allowing me to see all aspects of the installation and for sharing information about her company's philosophy and plans. I am also grateful to Dr Wale Salako, the head of farm and vet doctor, and to Zaccheaus Olawoyin, the biogas plant manager, for an informative tour of the site.

This report has been fact-checked by Avenam Links International, but the opinions contained herein are solely those of the DFID-contracted consultant.

Matthew Owen
29th June 2017

Case Study AD5: Kampala City Abattoir Biogas Plant, Uganda

Technology	Anaerobic digestion + power generation
Project developer	Makerere University and City Abattoir Traders Development Association, Kampala, Uganda
Location	Kampala City Abattoir, Old Port Bell Road
Type of digester	Temperature-controlled two stage digester
Year of commissioning	2012 (project started 2010)
Primary feedstocks	Wastewater and blood from abattoir
Engine size	30 kW_e (37.5 kVA)
Contact person	Joseph Kyambadde, Senior Scientist
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech Geert Jan Heusinkveld, Q Energy
Date of visit	9th May 2017

Project details

The City Abattoir is Kampala's oldest abattoir and is located close to the city centre on Old Port Bell Road. The site is owned by the Kampala Capital City Authority and managed by the City Abattoir Traders Development Association (CATDA).

Sida (Sweden) launched its Bioinnovate Africa Fund in 2010 and a successful application for funding for a biogas plant at the abattoir was made under its environment window by a consortium comprising Makerere University and CATDA. The bid was led by Dr. Joseph Kyambadde from Makerere's Department of Biochemistry and Sports Science, who had himself studied for a PhD at the Royal Institute of Technology (KTH) in Sweden in the mid-2000s and was one of several East African scientists who returned home and were then supported by Bioinnovate to develop bioenergy projects based on their overseas technical exposure. The Bioinnovate Fund is managed from the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi and is understood to be launching a second funding round shortly, to which Dr. Kyambadde intends to apply for a technology business incubation and commercialisation grant to enhance the biogas plant. An interim grant has in the meantime been secured from the Uganda National Council for Science and Technology (UNCST), under the National Science and Technology

Innovation Programme, to further optimize the AD process and evaluate possibilities for packaging the biogas and marketing the sludge as organic fertilizer.

The City Abattoir has no waste treatment facility. Solid wastes are transported to Kitezi landfill while about 400,000 l per day of liquid waste (mainly blood) are ejected into an open drain known as the Nakivubo Channel. The drain flows behind a neighbouring abattoir (run privately by Top Cuts butchery), which also discharges untreated wastewater into the same channel, which eventually drains into Lake Victoria 5 km away. This represents a significant pollution issue and the pilot AD plant was designed not only to produce biogas to generate electricity, but also to clean up a portion of this waste using an aerobic/anoxic sequencing batch reactor, integrated with a constructed wetland system.

The plant is interesting for its use of locally-available equipment. For a total cost reportedly below USD 200,000, the system uses components bought entirely within Uganda, except for a gas blower imported from Italy. The AD plant uses a two-stage batch digestion process (i.e. separate hydrolysis and methanogenesis). The wastewater is pumped in batches from the abattoir drain to four plastic holding tanks on a metal scaffold, from which it is gravity-fed to four hydrolysis tanks (2 x 10,000 l plus 2 x 5,000 l) for the first digestion stage. After a three day residence time these tanks are emptied via a small mixing chamber into the digester, and then refilled. The digester itself is a PVC bag of 108 m^3 volume, housed inside a locally fabricated insulated metal container for fluid containment and protection from the sun to avoid degradation of the PVC bag. The substrate is fed in from the top and the retention time in the digester is seven days. There is a void in the digester for gas collection so it is pressurised for delivery to a 70 m^3 gas storage bag, also housed in a protective structure. The digester is kept at 30 to 38^oC by a system of internal pipes circulating water heated with roof-mounted solar panels (one of which is broken, but the system still seems effective). The digester pH is reportedly between 5.5 and 6.5.

The biogas is piped to a 30 kW_e Lister dual-fuel engine (gas 70%, diesel 30%), passing en route through a moisture trap and a steel wool scrubber to remove hydrogen sulphide, which was reportedly changed on a monthly basis. The gas meter has broken but up to that point had recorded 766 m^3 of supply. The digestate is pumped into a concrete drying bed, into which overflow from the digester also flows.

The engine is operated at night to power the lights and fridges in the abattoir. CATDA does not pay for the power, but in return provides free water and day-time electricity to the biogas operation for the pumps, mixers and blowers. CATDA also donated the land on which the plant is constructed and provides site security.

Integrated with the AD system is a separate wastewater treatment facility for cleaning up an additional portion of the abattoir wastewater. The overhead tanks

that feed the biogas system also feed four 10,000 l sequencing batch reactors. These are open plastic tanks through which air is bubbled for nitrification and organic carbon removal. The liquid effluent spends 12 hours in each tank for nitrification and another 12 hours for denitrification, and is then released by gravity into a papyrus-planted sub-surface flow constructed wetland, and eventually back into the Nakivubo Channel. The papyrus was harvested and replanted in early 2017 as it had been growing well on the aerobically treated wastewater.

The plant has three workers whose salaries are covered by the UNCST grant. These are the Site Manager Dr. Robinson Odong (who has a PhD from Makerere University in Environmental Microbiology), Mr Bright Twesigye (an operator with a university degree in ICT) and a casual labourer. Mr Mohammed Nsubuga (Secretary to CATDA) oversees daily operations on behalf of CATDA, while Engineer Charles Ddungu provides engineering/mechanical support.

Efforts were made at one point to supply the biogas to operators of small-scale catering kiosks in the abattoir compound, but they requested free cooking stoves and these could not be provided due to financial constraints. Marketing of the digestate as farm manure is yet to be investigated, but so far any manure produced is readily accepted by farmers for a modest charge.

Photos

City Abattoir holding pen

Wastewater in open drain behind abattoir

Integrated AD & water treatment plant

Biogas storage bag

Digester gauges and gas meter
(on the structure housing the digester bag)

H_2S filters and dual-fuel engine

Digestate

One of the aerobic reactor tanks

Barriers and opportunities for replication

The Kampala City Abattoir biogas plant demonstrates that a functioning anaerobic digester can be built in Sub-Saharan Africa using components that are available locally. The plant also demonstrates how biogas production can be integrated with a wastewater treatment system.

The plant has not solved the abattoir's waste disposal problem, however, because it was developed as a pilot scale facility. The daily capacity of the system is around 10,000 l[20] and the parallel aerobic cleaning system can handle an additional 20,000 l[21]. This is less than 8% of the total abattoir discharge. But as a demonstration of technical potential, the system is convincing.

The project inevitably faces significant sustainability challenges, given that it was built using donor funds and continues to rely on grants to pay staff and carry out maintenance. One of the solar panels has broken, the gas meter does not function, rodents occasionally damage the gas storage bag, the constructed wetland system is

[20] Two 10,000 l plus two 5,000 l hydrolysis tanks, with a retention time of three days.
[21] Four 10,000 l aerobic reactor tanks with a retention time of 12 hours per tank.

semi-functional and the motor on the air blower (for the aerobic reactors) has blown once. Funds are only available to cover core costs and carry out critical repairs.

The main barrier to replication of the technology is therefore the absence of a commercial operating model. From a technical point of view, it has been demonstrated that there is capacity within Uganda to build a relatively low cost biogas plant that can ensure environmental compliance, boost energy security and potentially provide revenue from sales of electricity and fertilizer. There is a massive quantity of raw material available at the site and the concept could be replicated at other abattoirs in Uganda and beyond, but only if commercial partnerships are established between the owners of these facilities, the operators who manage them, and the developers of biogas systems. The failure of the government to enforce penalties for uncontrolled waste disposal further adds to the difficulty of establishing a commercially viable operation. If regulations against uncontrolled pollution are not enforced, managers of facilities such as abattoirs have no avoided costs of waste disposal.

From a technical perspective, Dr Kyambadde would like to research more effective ways of cleaning, drying and cooling the gas before it reaches the engine, and simple ways to measure and monitor gas quality. Otherwise the engine will be damaged and eventually break down. He is also is interested in testing the AD process with by-products from dairies, oil pressing, fruit juice processing and fish processing.

He is further interested in purification of the biogas to increase its methane content, which is critical for bottling of the gas as cooking fuel, as well as to protect the engine from corrosion.

Acknowledgements

We are indebted to Joseph Kyambadde for his kind welcome and tour of the AD plant in Kampala, and for the invaluable information that he provided. This report has been fact-checked by Dr Kyambadde but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
12th June 2017

Case Study AD6: James Finlay Kenya Biogas Plant, Saosa Estate, Kericho, Kenya

Technology	Anaerobic digestion with heat + power generation
Project developer	James Finlay (Kenya) Ltd
Location	Saosa Tea Estate, Kericho (-0.353232, 35.287474)
Type of digester	Sauter SB Midi Multi Batch Lagoon Digester
Year of commissioning	2014
Primary feedstocks	Spent tea from soluble tea factory
Engine size	160 kW_e /170 kW_{th}
Contact person	Hugo Douglas-Dufresne, Technical Director
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech Ankit Agarawal, LTS International
Date of visit	11th May 2017

Project details

The James Finlay Saosa Tea Estate, located at 2,200 m above sea level near Kericho, produces about 23,000 t of tea per year. The vision of Finlays (and its parent company Swire) is to be completely self-sufficient in energy by 2030. As part of this strategy, the company has invested in a variety of clean energy technologies at Saosa that include five mini-hydro power stations (the largest being 1.1 MW_e), a CHP steam turbine plant (700 kW_e), a passive solar house for drying operations, a 30 kW solar PV system operating a pulley-based transport system to ferry tea bags to the processing plant and a 160 kW_e biogas plant.

The biogas plant was developed to:

1) generate power for the estate's internal grid;
2) supply heat for pre-processing applications in the tea factory and to heat the digester itself; and
3) generate slurry as fertilizer for the tea plantations

Other factors contributing to the economic viability of the plant (with a five year payback period) are the availability of free feedstock, avoided costs of waste disposal and investment deduction tax allowances at 150%.

The plant was set up and commissioned by the German EPC contractor AKUT in April 2014. It has a substrate feeding capacity of 28 t/day and a dual-fuel 160 kW_e CHP Deutz engine. The site has the capacity to expand to 70 t/day input for additional digesters and a larger engine with 800 kW_e output.

Operating up to 22 hours per day, the current plant can potentially generate almost 1,300 MWh of electricity per annum. 24 hour operation is not possible as the engine protection circuits reportedly cut in up to seven or eight times per day due to outages and surges in the grid.

The digester is fed with spent green and black tea (a by-product of soluble tea production). 4 t/week of cow dung are also added to stabilise the bacteria. This input is organically certified and the digestate can therefore be used on the organic tea plantations. There are plans to add a second digester to accommodate non-organically certified feedstocks such as flower cuttings and septic tank waste.

The spent tea is pumped into the digester via a BioMix feed auger, and undergoes pre-mixing with the digester contents before being fed into the main tank. Dry matter content is maintained at no more than 9-10%, which avoids clogging of the pipes. The average daily feed rate is about 20 t. All technical equipment is located in a single 20 foot container: pumps for mixing and feeding, panels for measurement and control, compressor for pressurized air, register for water heating system, distribution register for feed and transport pipes, heat exchanger and electrical supply devices. The substrate from the inbound mixer passes through valves in the container and is pumped into the digester via two automated spray nozzles. This approach (as opposed to traditional internal mixing) ensures that different stages of the digestion process take place in different layers within the digester. Active (and not completely homogenised) biomass particles sit at the top and the substrate discharged from the lower area is almost completely digested. Some operators believe that this enables higher gas yields to be achieved, although it is not yet definitively proven that spraying in the substrate rather than mixing internally can deliver this benefit. The circulating substrate is warmed to 38-42°C via an externally positioned heat exchanger, which derives its heat from the dual fuel gas engine. Thus all pumping, mixing and heating equipment is located *outside* the biodigester. This innovative design approach greatly eases access for repair and maintenance.

The digester holds approximately 1,600 t (1,435m^3) of waste and up to 1,700 m^3 of gas. Retention time in the digester is 100 days and the pH is 7.2 under normal operation. Daily gas production is 400 to 625 m^3, depending on the nature and quantity of feedstock. The quality of gas produced is constantly monitored using a gas analyser. It consists primarily of CH_4 (52%) and CO_2 (40%). It also contains hydrogen sulphide (H_2S) and this is partly removed by allowing a controlled amount of air into the digester to encourage growth of sulphide-oxidising bacteria at the

gas-substrate interface. The methane-rich biogas is channelled through high density polyethylene (HDPE) pipes to a dual fuel gas engine. The pipes run underground to cool the gas and are angled upwards to allow condensed water to drain out at the bottom. The digestate is discharged into a nearby lagoon.

The CHP engine is preinstalled within a ‘plug and operate’ container and connected to an alternator producing 160 kW_e of electricity. A heat exchanger combines the heat from the exhaust and the engine’s cooling circuit into a single heat stream of around 170 kW_{th}. Electricity production was 946 MWh in 2015 and 831 MWh in 2016, with a 2017 projection of 860 MWh, subject to efficient replacement of the alternator. This represents 65-74% of the engine’s rated maximum which corresponds well to the usual engine operation at 75% capacity (120 of 160 kW_e)

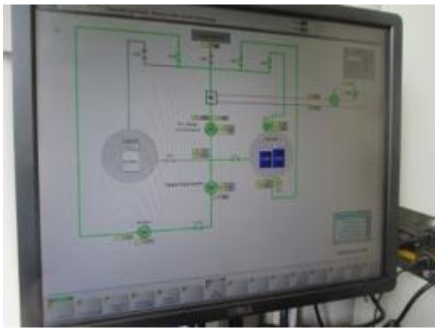
The capital cost of the plant (incl. installation) was USD 2 M and the payback period is reportedly less than five years. Replacing synthetic fertilizer with digestate probably represents the largest economic benefit for Finlay, though no actual values for power, heat or digestate were available.

The plant is overseen by one trained engineer and is operated in three shifts of eight hours by two technicians. The system is completely automated and the plant can be monitored and controlled remotely. The engineer on-site is technically competent with a background in mechatronics engineering. He independently undertook a one month biogas training programme at the University of Stuttgart and thereafter underwent a week’s training on the installed biogas plant.

Photos

Site view

Feeding area

 Feeding belt	 Biomix feed augur
 Heat exchanger	 Control system (SCADA)
 Digester interior	 Deutz dual fuel CHP engine
 Heat transfer pipes from engine	 Slurry lagoon

Barriers and opportunities for replication

The James Finlay AD plant has been an overall success, with the company keen on adding additional units based on the positive results. Finlay undertook a five year programme of pre-testing in a smaller demonstration digester to ensure that the feedstock would be appropriate and the technology suitable, well in advance of the investment decision. A shorter practical testing period of less than one year alongside lab tests would be sufficient, however. This presents something of a replication barrier since smaller companies might not have the resources to set up pilot plants to test and run their feedstock to ensure viable and dependable biogas production.. The main technical barriers to replication relate to the high demands of maintenance, repair and operational sophistication associated with this top-of-the-range German system. Non-technical barriers concern optimising the economic use of the various end-products (power, heat and digestate).

The plant has been running mostly without interruption for three years, although by bad luck the engine was not actually working at the time of the visit as an electrical surge had fused the breaker and damaged the alternator. This problem will be solved by having dual breakers in series and changing the breaker contacts more often. Ideally, a grid protection relay would be installed prior to the breaker to monitor different grid parameters (such as frequency, voltage, etc) and automatically turn off the breaker milliseconds before any voltage spike. Delays encountered in ordering replacement components from Germany, compounded by Kenya Customs hold-ups, highlight an important challenge around maintenance of imported technology. With the technology providers based in developed countries and no local availability of sophisticated spares, a plant might be forced to shut down for weeks at a time, with significant effects on cash-flow. Replication of such technology therefore ideally requires local presence of technology providers, but so far none have found it economically viable to set up a base in SSA (with a few exceptions in South Africa such as Anaergia).

Managing the operations of such a plant requires a technically qualified team on site, with back office support and solid engineering capacity. While Finlays has the financial muscle to hire competent staff to operate and maintain the equipment, replication by smaller players would present significant capacity challenges.

Finlays places value on three product streams: heat, power and digestate. This is an important combination that builds up the economic case for the plant. It would be important for other potential AD operations to look to multiple value streams from electricity, heat and fertilizer to make a viable economic case.

Finlays itself does not necessarily have an incentive to promote replication of the AD technology, given that it is a tea company not a renewable energy provider. There is

nevertheless potential for an extension of the current AD site at Saosa and for replication by other tea estates and by small agri-businesses. Anaerobic digestion using tea waste, however, requires a soluble tea plant located on-site - of which only very few exist in Africa. If there was a subsidiary or local agent of European biogas companies in Kenya offering service and back-up support, it seems probable that this would favour replication.

Acknowledgements

We are indebted to Hugo Douglas-Dufresne for his open welcome and informative discussion of Finlay's biogas plant and the company's wider approach to renewable energy. We would also like to thank Dennis Cheruiyot for his detailed tour of the plant, taking us through each step of the process. We appreciate James Finlay's impressive commitment to meeting energy self-sufficiency targets, and it was very kind of its staff to share their best practices and lessons learnt.

This report has been fact-checked by James Finlays (Kenya) Ltd., but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen, Ralph Ripken and Ankit Agarwal
15th June 2017

Case Study AD7: Tropical Power Anaerobic Digestion Plant, Gorge Farm, Naivasha, Kenya

Technology	Anaerobic digestion with heat and power generation
Project developer	Tropical Power UK (for Biojoule Kenya)
Location	Gorge Farm, Naivasha
Type of digester	Batch hydrolysis
Year of commissioning	2015
Primary feedstocks	Vegetable processing waste
Engine size (MW_e/MW_{th})	1.3 MW_e/1 MW_{th} + 1 MW_e[22]/1 MW_{th}
Contact person	Mike Nolan
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech Ankit Agarwal, LTS International
Date of visit	12th May 2017

Project details

The Tropical Power anaerobic digestion plant is located at Gorge Farm, 2,100 m above sea level on the south side of Lake Naivasha in Nakuru County, 100 km north-west of Nairobi. The 800 ha farm is owned by the Veg Pro Group, a major exporter of fresh produce and cut flowers.

The project was developed by Tropical Power UK Ltd and is one of the largest biogas plant in Sub-Saharan Africa outside South Africa at 2.3 MW_e. It is understood to be owned 50:50 by Tropical Power and Bharat and Umang Patel, who also own Veg Pro, giving the feedstock provider a vested interest in the project's success.

The plant was developed to provide multiple economic benefits:

1. Power for the Veg Pro agricultural operation;
2. Surplus power sales to the national grid;
3. Slurry for Veg Pro to substitute for synthetic fertilizer; and

[22] Rated combined engine size is 2.8MW_e, but due to the altitude of 2,100m the actual capacity is only 2.3MW_e

4. Heat for the digester and a surplus sold to warm the neighbouring greenhouses

The plant was engineered commissioned by Tropical Power in 2015 with components from IET Siemens (switchgear and transformers), BioG (material handling), SLP GmbH (instrumentation and control systems) and Paulmichl (agitators and stirring equipment) and Jenbacher (CHP gas engines rated at 1.3 MW_e and 1 MW_e). The installed capacity of the plant's internal electricity equipment is 130 kW_e.

At full capacity the digester can be fed with up to 120 t/day per day of agricultural residue such as maize stalks and cobs, and residues from broccoli, carrot and onion. The average feed rate is considerably lower though due to feedstock constraints. Dry matter content varies from 9% (broccoli) to 24% (maize stalks), while the organic dry matter content (or volatile solids) is 80-95%, leading to an organic loading rate of up to 4.8 kg of volatile solids per m^3 per day for maize stalks and 1.7 for broccoli.

Feedstock availability is constrained by the limited output of the Veg Pro operation. Naivasha is Kenya's leading floriculture area so Tropical Power has been investigating the use of supplementary lignocellulosic rose waste. A lab-scale steam exploder has already been trialled to separate lignin, cellulose and hemi-cellulose and further experiments with rose waste were ongoing at the time of the visit. The impact of pesticides applied to the roses both for the digester and slurry needs to be carefully considered. Tropical Power also secured a 2016 grant from the Prosperity Fund to explore other feedstocks and has an ongoing programme investigating water hyacinth and dryland crassulacean acid metabolism (CAM) plants such as *Euphorbia spp*., though this would be for additional sites rather than Gorge Farm.

The feedstock is batch-fed into the first of two hydrolysis tanks. Liquid is added from the storage tank; no fresh water is put into the system. Hydrolysis takes place in the first tank and the material is then pumped into the second tank which acts as a buffer to the main digester. Two hydrolysis tanks were installed to deal with the fibrous maize stalk material. The substrate is then fed into the main digester at a rate which varies according to gas consumption at the CHP unit.

The plant was built to a standard European specification designed to use ensiled maize as feedstock. The ensiling process breaks down the waxy coating on the outside of the plant. The plant in Naivasha is fed daily with freshly harvested material and the presence of the waxy coating tends to make the material hydrophobic, giving it a spongy consistency and a tendency to float. The original mixing system in the first hydrolysis tank therefore had to be replaced with a more suitable technology. The mixers in the second hydrolysis tank and the main digester were not affected.

The retention time is 16 days at 38.6°C and pH 8. The digester has a volume of 5,652 m^3 and typical daily gas production of 5,000 m^3 (requires confirmation), depending on the feedstock. The quality of gas produced is constantly monitored. It consists primarily of CH_4 (52%) and CO_2 (47%). It also contains 5 ppm of H_2S and this is partly removed by allowing a controlled amount of air into the digester (up to 3% of the produced biogas) and by adding iron powder. The air intake encourages growth of sulphide-oxidising bacteria at the gas-substrate interface.

The digestate is pumped into a small final holding tank (759 m^3), designed to store slurry for one day, in which any additional biogas is captured. Slurry holding tanks in Germany must be designed to store up to six months of digestate.

The biogas is piped to the gas conditioning skid where it is cooled to 5 degrees to remove moisture. The CHP engines are installed in 'plug and operate' containers and connected to alternators producing 1.3 and 1.0 MW of electricity at a reported efficiency of 41%. The output can vary, however, depending on available gas volume. At the time of the visit only the 1.3 MW_e unit was operating due to limited biogas production. Electricity is fed to the farm, and any surplus to the national grid, while a heat exchanger in the engine cooling circuit takes hot water into the digester at 80°C and there are plans to sell surplus heat to a neighbouring flower farm to warm greenhouses at night.

The capital cost of the plant was reported by the Site Manager as USD 3 M per MW (USD 6.9 M for entire 2.3 MW_e plant), which could apparently be reduced by using smaller pre- and post-digester tanks and cheaper components. The feasibility of these measures would need to be evaluated by technology providers. Higher capital costs are partially caused by the concrete work to ensure safety in a seismic region and technical protection of the alternators from an unreliable grid. Operational costs are comparatively high at USD 13.50/MWh so it is assumed that electricity is sold to VegPro at something between this price and the utility's tariff of USD 18-22/MWh. Any surplus electricity is sold to the grid at USD 0.10/kWh under a Power Purchase Agreement and hot water will be priced at USD 0.04/kWh_{th}. The digestate contains 5 kg of nitrogen per 1,000 l and is used as fertilizer in Veg Pro's operation, where it is reportedly saving the company 30% of its total fertilizer costs and a remarkable 8-10% of total farm running costs.

The plant is overseen by the Manager of Operations, a UK-trained engineer, and is operated 24 h per day by two technicians. The system is completely automated and the plant can be monitored and controlled remotely if necessary. The engineer on-site is technically competent with a wealth of experience from the energy industry in Africa, Two lab technicians constantly monitor the gas and slurry quality, and undertake tests on new feedstock.

Photos


Feedstock


Feeding area

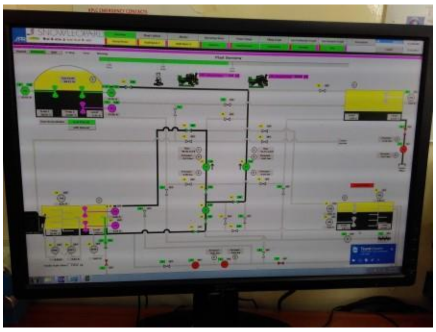

Feeder pump to tank 1


Site view with slurry storage tanks


View of engine area


Engine container


Jenbacher gas CHP engine


Control system

Barriers and opportunities for replication

The Tropical Power plant at Naivasha is a successful demonstration of the potential of anaerobic digestion to be a technical and commercial success in Sub-Saharan Africa, provided that certain pre-conditions are met. An important element in the successful operation lies in the well trained, experienced and motivated personnel, who understand local operating conditions and appear to have strong problem-solving skills to overcome barriers and improve system performance. The company also has full control over all the feedstock and has ensured the security of supply because the feedstock owner has a significant equity stake in the operation. It also has two anchor loads for the products from sales of power and slurry to Veg Pro, with additional income streams from selling power to the grid and (planned) sales of hot water to a neighbouring farm. With two income streams the operation has reportedly achieved profitably. The additional income stream from heat sales would represent a surplus. It is notable, however, that one income stream alone would probably be insufficient and heat sales have not been achieved yet.

Barriers to replication include finding sites with sufficient concentrated feedstock and on-site demand for electricity, heat and/or fertilizer. Securing sufficient feedstock has been an ongoing challenge for Tropical Power and only one engine was operational during the visit as a result. Daily substrate requirements need to be carefully calculated for biogas projects of similar size. Kenya's relatively low feed-in tariff of USD 0.10/kWh is an important policy barrier as it makes commercial viability more difficult to achieve. Finding a viable use for the heat has also been challenging and this income stream is only now being developed.

Technical barriers to replication concern the adaptation of the European design to the African context and the reliability of the digester mixers. The technology is sophisticated and expensive, and the Site Manager has identified a number of options for cost reductions. Top-of-the-range digestate mixers from Germany were being installed in the first hydrolysis tank without prior testing on non-ensilaged maize stalk feedstock. Due to floating properties of spongy components of the maize stalk the mixers broke. Capital costs could potentially be reduced by using less stainless steel in the various tanks. The high demands of operation and maintenance associated with this top-of-the-range German system further add to the technical barriers. Reducing the cost of European biogas equipment and adapting it better to the African context is a useful avenue to pursue for replication.

Although not exactly 'pro-poor', the plant has brought benefits from job creation, improved crop yields, income security, development of indigenous technical capacity, reduced use of water and synthetic inputs, and so on. With sophistication also comes full automation and this is a significant benefit for day-to-day operation, provided

that site staff are properly qualified and trained. While Tropical Power has the financial muscle to hire competent personnel to operate and maintain the equipment, replication by smaller players would present significant capacity challenges.

Tropical Power is interested in exploring smaller and simpler biogas opportunities in the 200-500 kW output range. A particular opportunity has been identified with crassulacean acid metabolism plants as the supply in the drylands is almost unlimited. Increasing the number of potential feedstocks, including lignocellulosic materials, would help increase the replication potential of biogas in Africa. Tropical Power's research on viable methods for separating lignin, cellulose and hemi-cellulose in feedstocks such as rose waste represents a possible first step.

Acknowledgements

We are indebted to Tom Morton and Mike Mason for facilitating a visit of Tropical Power's plant and to Mike Nolan for his open welcome, informative discussion and detailed tour. We appreciate the company's impressive commitment to biogas development in Kenya, and it was very kind of its staff to share their best practices and lessons learnt.

This report has been fact-checked by Tropical Power, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen, Ralph Ripken and Ankit Agarwal

18th July 2017

Case Study AD8: Olivado Kenya (EPZ) Ltd. Biogas Plant, Murang'a Kenya

Technology	Anaerobic digestion with heat + power generation
Project developer	Olivado EPZ Ltd.
Location	Murang'a County, Kenya (-0.769491, 37.258308)
Type of digester	2 x recirculation mixed industrial digesters
Year of commissioning	Under construction (May 2017)
Primary feedstock	Avocado skins, stones, pulp and process water
Engine size	Planned 125 kW_e + 320 kW_e (plus at least 600 kW_{th})
Contact person	Hannes Muntingh, Biogas Project Manager
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech Ankit Agarwal, LTS International
Date of visit	12th May 2017

Project details

Olivado operates an avocado processing plant within an Export Processing Zone in Murang'a County, Kenya, adjacent to the Tana River near the 'Kwa Samaki' road junction. The company's main product is organic, food grade avocado oil for export. Around 11% of the fruit/weight is extracted as oil and the remaining 89% is waste in the form of skins, stones (seeds) and pulp. Process water used for oil extraction also adds wet waste stream rich in pulp particles and some oil not extracted. The company saw the potential to process this material using anaerobic digestion, not only avoiding waste disposal costs but also creating electricity and heat.

Olivado has recruited an experienced biogas specialist to lead the development of the plant. Two digesters have been constructed and one has been started up successfully. The gasholder membrane of the second digester is now due for installation. Once this is done, the second digester will be started up using effluent from the first for inoculation. Each is designed to accommodate 1,400 m^3 of substrate and 1,400 m^3 of gas.

The gas will be upgraded to run two natural gas co-generators which will generate up to 400 kW_e to meet the factory's total electricity requirements. Meanwhile the cooling water and exhaust heat (thermal output of at least 600 kW) will be used to

bring process water to 75°C, replacing a 120 kW electric immersion heater that currently accounts for 44% of the company's total power consumption.

Any excess gas will be compressed and bottled on site for use as vehicle fuel as well as commercial purposes (as an LPG substitute). The co-generators and biogas upgrading and bottling plant are currently being manufactured and will be due for shipping by the end of June 2017.

The Olivado project is particularly interesting for its technological approach. From the outset, the aim was to develop a system that would be both economically and technically viable for replication in Sub-Saharan Africa. Local expertise and locally available materials have been used wherever possible. In many areas of construction specific to this technology, time was taken to build local capacity. While building on the best elements of standard AD technology, Olivado is using a combination of local design modifications and less expensive materials from Asia to achieve a significantly lower build cost. For example, the digester tanks are below ground and lined with plastic rather than built of concrete; and computer control systems will initially be avoided in favour of manual operations, with data provided by key monitoring sensors. This also helps build further understanding of the technology for successful operation by local plant operator. Some elements of German technology will still be required, such as the digestion concept, CHP design, CHP equipment, components to endure harsh environments and expertise specific to imported equipment.

Once the pilot plant is fully operational and expectations are verified, Olivado plans to pitch a commercial AD model to other agro-industries. It aims to build, own and operate biogas plants that will dispose of troublesome biomass wastes, either selling the power (and potentially heat) back to the feedstock provider or, where applicable, upgrading and bottling the gas for commercial energy supply to large-scale consumers. Modular, mobile digester units are being considered for the commercial replication model, as they can be installed quickly to whatever scale is required and can be considered as a movable asset.

Olivado will explore the biomethane model internally first, by converting its own company vehicles to run on upgraded biogas, while exploring a wider market for compressed, bottled gas as a substitute for LPG. While there are no revenue expectations from sales of the digestate, this also looks like a valuable by-product worth factoring into the business plan and research is underway to establish the market potential for this bio-fertiliser.

Photos

Avocado processing line

Avocado waste – skins and stones

Completed digester (at rear)

Second digester (under construction)

Barriers and opportunities for replication

While it is too soon to conclude that the Olivado AD venture will be a commercial and technological success, the indications are certainly positive, given the leadership of a well-qualified manager and the combined savings envisaged from avoided waste disposal and the on-site production of both electricity and heat. Evidence from other sites suggests that securing two or more revenue streams (or cost savings) in this way is a requirement for AD plants in Africa to succeed commercially, in the absence of the attractive feed-in tariffs and other clean energy subsidies that are available to counterparts in Europe.

Barriers to wider adoption of the technology in general include the high investment cost, challenges in dealing with local financing institutions for unfamiliar anaerobic digestion investments and the operational sophistication of standard biogas technologies. The investment cost challenge is being tackled by Olivado through the adaptation of German design concepts using simpler and more affordable approaches. The operating challenge will be tackled by building, owning and operating any future plants on behalf of clients. But in order to pursue its planned replication model, Olivado will need to generate evidence that the concept will be

commercially feasible with a variety of alternative feedstocks available from small- to mid-sized agribusiness operations in Kenya, and there will need to be a financing model that works for both client and service provider. Trials on avocado ran for 18 months and similar long-term tests could be envisaged with other potential feedstocks. Similar extended research using other feedstock could be an area of useful research that would validate the model for wider adoption. Reliable lab facilities would also be of assistance when analysing potential new feedstocks.

Acknowledgements

We are indebted to Hannes Muntingh for his open welcome and informative tour of the Olivado AD plant, late on a Friday afternoon, and for the kind permission of the company Director Gary Hannam for the tour to go ahead. We appreciate that Olivado is passionate about biogas and sees great potential in the technology, and is rightly careful to screen visitors and protect information of commercial value.

This report has been fact-checked by Olivado, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen, Ralph Ripken and Ankit Agarwal
29th June 2017

Case Study AD9: Kilifi Plantations Ltd. Biogas Plant, Kenya

Technology	Anaerobic digestion + CHP
Project developer	Biogas Power Holdings (East Africa) Ltd.
Location	Kilifi Plantations Ltd., Kilifi, Kenya
Type of AD system	Complete mix
Year of commissioning	2007
Primary feedstocks	Sisal waste, mango residues, cattle slurry
Engine size	2 x 75 kW_e
Contact persons	Chris Wilson, Managing Director Robert Anyoso, Engineer
Emails	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant
Date of visit	7th April 2017

Project details

Kilifi Plantations is a 1,300 ha mixed sisal and dairy operation located just south of the town of Kilifi on the Kenyan coast. The owner, Chris Wilson, was out of the country when the consultant visited, but kindly delegated his engineer (Robert Anyoso) to host the visit and provide project information.

Biogas Power Holdings (East Africa) Ltd was set up as a joint venture of Kilifi Plantations Ltd (KPL) and the German companies agriKomp and Schnell Zündstrahlmotoren to generate power from biogas for sale to KPL, on whose land it is installed. It is understood that the power generating company has since transitioned to full KPL ownership.

A 850 m^3 biogas digester was built in 2007 (750 m^3 for substrate and 100 m^3 for gas storage). The cost was KES 40 million (USD 600,000) with 50% co-funding from GIZ (via agriKomp). It is linked to twin 75 kW_e gas engines for power production. The power is sold to KPL while heat captured from the engine cooling system is used to keep the digester at 32-40^oC. The digestate is given free to KPL as fertilizer.

Based on experimentation and technical advice from the equipment supplier and the Nairobi-based consultant Guenther Haustedt, the feedstock combination is 14:3:2, sisal waste : mango waste : cattle slurry. The sisal comes from KPL's own decorticator. The mango is the by-product of an off-farm juicing operation, which was required by

environmental regulations to find a safe way to dispose of its waste and brings the pressed mango residue to the biogas plant. The cattle slurry is supplied by 400 heifers stalled overnight in a large, hard-floored shed. The KPL milking operation is carried out at satellite sites around the estate and the manure from the milking cows does not therefore get fed into the system. This doesn't seem to be a problem, given that cattle slurry is the smallest feedstock component. No bacteria have been added to the digester since initial commissioning.

Gas production averages around 375 m^3 per day, which is sufficient to run the two engines for about 15 hours (based on consumption of 25 m^3/hr).

Biogas Power Holdings is understood to sell electricity to KPL at KES 16/kWh (USD 0.15/kWh), which includes an allowance for the value of the feedstocks (slurry and sisal waste) that KPL provides. This compares with a grid tariff of KES 18-22 kWh (USD 0.17-0.21/kWh), depending on the fuel factor (itself dependent on the amount of diesel-generated power being fed to the national grid in the billing month). The power from the biogas plant is therefore cheaper than grid power. Grid feed-in is less attractive than sales to KPL as the Kenya Power FiT is only US$ 0.10/kWh (KES 10.3) - and in any case a minimum output of 200 kW is required for a power purchase agreement.

Power production has averaged 14 MWh over the ten years of operation, suggesting gross monthly income of KES 224,000 (currently USD 2,150).

This is a sophisticated biogas plant with a high degree of automation, for example in the mechanical mixing and heating of the digestate, and in the operation of the engines (which can be remotely monitored from Germany by the supplier). The gas supply is sufficient for one engine to be run for 17-18 hours each day and, as a result, KPL's power bill has reportedly fallen by 60%. Apparently with more mango waste the gas output would increase and the engine could be run 24 hrs/day. If the mango stone (kernel) was crushed and pre-processed it would reportedly raise the gas-generating potential further, as it would permit fat to be released.

The engines were second-hand when installed and have not been performing efficiently. One was out of service at the time of the visit. The company is in the advanced stages of commissioning a larger biogas plant with more efficient engines at the same site, with co-funding from UNIDO (contact Bart Fredericks: b.fredicks@live.nl). This upgraded system is expected to have a 2,500 m^3 digester and a 250 kW dual fuel engine, permitting diesel operation when gas pressure is low. The equipment supplier is not yet confirmed, but likely to be either agriKomp (contact Elisabeth Lehmann) or the South Africa branch of Anaergia (contact Dennis Thiel in Cape Town), which has previously supplied technology to Bio2Watt.

In the upgraded system, heat from the engines will be used to pre-heat water for KPL's milk pasteurisation plant, reducing the need to use the firewood-fuelled boiler that currently does the job.

Photos

Sisal processing

Sisal waste

Mango residues

Cattle slurry


Slurry in pre-pit


Biodigester


Sisal waste in feed hopper


Post-pit digestate


Engine room


Boiler for heating pasteurising water (new system will replace)

Barriers and opportunities for replication

The original AD plant at KPL is believed to have been the largest of its type in Sub-Saharan Africa (outside South Africa) at the time of installation in 2007. It was very much a pilot operation and received financial support from GIZ to demonstrate the business case from the use of modern European biogas technology for power production. It has turned out to be a successful enterprise that generates sufficient revenue from electricity sales to return a small profit, based on a relatively high inter-company tariff (KES 16/kWh) rather than the utility's feed-in rate (equivalent to only KES 10.3/kWh). Replication would be possible at other sites of captive demand to displace grid power, especially in agribusinesses seeking to avoid mains electricity that is either costly or unreliable (necessitating the use of back-up gen-sets).

Relying solely on power sales could be a precarious business model, however, and KPL benefits also from the avoided disposal costs of sisal waste and the unquantified value of the digestate that is applied on the farm. Heat generation is foreseen as a minor additional output from the upgraded system and will displace some firewood costs.

The three greatest impediments to replication are probably lack of reliable feedstock supply, high capital costs of the equipment and insufficient managerial and technical capacity to operate and maintain such systems (especially in the absence of in-country suppliers of spares and technical support). These barriers are likely to mean that the technology is for the time being confined to relatively large commercial operations with the necessary financial, managerial and technical capacity, though the potential exists to install plants with lower output on smaller farms, to correspond with more limited feedstock volumes and smaller power requirements. Such expansion to smaller businesses may require modification of the German technology to make it more affordable for the African context.

Acknowledgements

I am indebted to Chris Wilson for his welcoming attitude to our request for a site visit, and to Robert Anyoso for kindly showing me the operation and providing invaluable information. We hope that the information generated will help inform a constructive contribution from DFID that leads to the replication of this type of modern bioenergy technology in the African countries that the BSEAA research is expected to cover.

This report has been fact-checked by Chris Wilson but the opinions contained herein are solely those of the DFID-contracted consultant.

Matthew Owen
13th June 2017

Case Study AD10: Mkonge Energy Systems / Katani Ltd. Biogas Plant, Hale, Tanzania

Technology	Anaerobic digestion + power generation
Project developer	Mkonge Energy Systems for Katani Ltd.
Location	Hale Sisal Estate, Tanga Region, Tanzania
Type of digester	Complete mix industrial digester
Year of commissioning	2007
Primary feedstocks	Sisal decorticator waste and wash water
Engine size	2 x 150 kW_e
Contact persons	Gilead Kissaka, General Manager, Mkonge Energy Systems Francis Nkuba, Executive Director, Katani Ltd.
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	18th May 2017

Project details

Katani Ltd. is one of Tanzania's largest sisal producers and owns five estates[23] covering 26,000 ha in the north-east of the country (out of 46 in the whole of Tanzania). The company is owned by Mkonge Investment and Management Company (51%) and the National Social Security Fund (49%). The sisal is grown by 1,270 smallholder farmers on plots (within Katani's land) that range in size from 6 to 200 ha. They sell their sisal to Katani for processing at one of the company's ten decortication plants.

50% of the sisal plant is marketable in the form of leaves (the remainder comprises the bole). These leaves yield 4% fibre from the decortication process, and the farmers are paid by Katani Ltd on the basis of this marketable percentage. The remainder of the leaves, comprising 85% water and 11% pulpy waste (12% organic dry matter) is discarded as waste. At Katani's Hale sisal processing plant, this becomes combined with 45,000 l/hr of washwater to yield green liquefied mixture of water, pulp and some fibrous leaf strands.

[23] Hale, Magunga, Magoma, Mgombezi and Mwelia.

In 2006, Katani benefitted from USD 1.5 M in support from the UN Common Fund for Commodities (USD 928,000), UNIDO (USD 226,00) and the Government of Tanzania (USD 350,000) to set up a biogas plant that would convert 65 t/day of this waste to 1,800 m^3 of biogas for the production of electricity.

This was the world's first sisal-based AD plant. A subsidiary known as Mkonge Energy Systems (MES) was created to own and operate the facility and sell power to Katani. Katani itself has a 75% stake in MES and the balance is owned by the German firm BioEnergy Berlin (BEB), which acted as the project's engineering, procurement and construction (EPC) contractor.

The plant includes a combination of locally-built steel tanks and Jinan (Chinese) dual-fuel engines and control systems. It comprises a 50 m^3 collection tank, 300 m^3 hydrolysis tank, 1,700 m^3 digester, 350 m^3 floating drum gas tank and 500 m^3 digestate tank. The plant also has a hydrogen sulphide cleaner, two 150 kW_e engines to generate power, a heat exchanger with water circulation system to heat the digester to 35-37^oC, and a water cooling tower. Total plant cost was around USD 800,000, with significant additional costs for project design, management and implementation. One engine was initially installed and a second was added in 2008 for an additional $135,000.

The plant is designed primarily to produce electricity. This is used first for internal operations within the plant (to power five pumps, two 15 kW digester mixers and other smaller appliances) and the surplus is sold to Katani at 15.7 US cents/kWh (a nationally prescribed tariff) for use in the adjacent processing factory. The decorticating machine alone requires 150 kW_e. The heat has no value other than for heating the digester, and the digestate has so far not been marketed.

There are four trained operating staff at the site and about ten security guards. The operators were training on site by BEB at the time of installation. Some staff have since benefitted from study tours to the Netherlands (one person) and China (four people).

This is a pilot plant and the first in the world to convert sisal waste to biogas. As such, it has been a dynamic learning experience for Katani, MES and BEB. A number of operational challenges have arisen.

For example, gas output was lower than anticipated as total volatile solids in the feedstock were closer to 3% than the 6% planning figure. Daily gas output was therefore 50-300m^3 rather than the anticipated 1,800 m^3 (averaging 63 m^3 of gas per tonne of feedstock between 2007 and 2011). Feedstock input was also significantly lower (1-6t/day) than the expected 65 t/day due to under-sizing of the pre-processing equipment, especially a hammer mill that was to have been used to chop

the fibre. The mill was replaced with a screw squeezer and screen cage, though these were not working at the time of the visit.

With the screw squeezer and screen cage fibre remover not functional, the feedstock only passes through rudimentary sieves and grates, resulting in long fibres entering the AD system. This has led to build-up of a thick surface mat in the collection tank and is probably the cause of the recent breakdown of the pump that transfers the feedstock to the hydrolysis tank. It may also have contributed to the reported frequent breakdown of the stirrers in the collection tank and hydrolysis tank.

One of the engines is also currently out of service due to lack of various spare parts. This means that the system does not have sufficient installed capacity to operate the 150 kW_e decorticator. When placed under load, the frequency drops and the generator eventually stops working. The records kept by MES operators show an average load of only 80 kW_e during the first five years of operation (2007-2011)[24], suggesting that the decorticator has in fact rarely been powered using the AD plant and most of the time it must have been running mainly on mains power, with the AD electricity as supplement. Assuming one 8 hour working shift per day, the engine would have ran for an average of 98 days per year during the same five year period to 2011. Records post-2011 are incomplete. Total electricity production between 2007-2011 was each year below 3% of total possible production and below 1% since 2012.

Another operating challenge relates to rusting of the steel tanks. External rusting is probably due to the humid coastal air, while internally there is deterioration caused by the H_2S content of the biogas. Lastly, a Chinese computer control system broken in 2014 and has not been repaired, meaning that important heat and pressure parameters can no longer be monitored.

MES and Katani have realised the problems caused by the low volatile solids content of the feedstock and the high fibre content. Solutions that they propose include a dry decortication system to increase total solids and reduce long fibres, redesign of the mixers to position them externally on the tanks for easier access and repair, an additional hydrolysis tank for pre-preparation of larger feedstock volumes and a single 250 kW_e engine that is large enough to power the decorticator.

Additional AD plants are envisaged for other Katani estates and the management is considering a system of concrete lagoons rather than replicating the steel tank model that has been used at Hale.

[24] 315 MWh from 3,926 engine hours.

Photos

Sisal processing line

Decorticator waste (sisal pulp & wash water)

Screw squeezer (out of service)

Screen cage (out of service)

Rudimentary sieving of fibrous matter

Disposal of excess waste water & pulp

Collection tank (with fibrous mat)

Hydrolysis tank (left) fed by collection tank (bottom right)

Digester tank with twin mixers

Gas storage tank

Hydrogen sulfide filter

150 kW_e engine

Barriers and opportunities for replication

The Hale AD plant has successfully demonstrated that sisal waste can be used to produce biogas and generate electricity. With sufficient care to avoid excess water content in the feedstock, a single factory can produce enough power to operate a decorticator machine and offer surplus for other estate operations or worker housing, potentially reducing direct operating costs of a sisal estate by up to 40% through electricity savings.

The tariff offered in Tanzania for biogas-derived power is relatively attractive, but the difficulties being experienced by the project managers in keeping the plant functional suggest that even this income is insufficient to cover ongoing operation and maintenance costs. It is not known if Katani actually pays MES for the power that is produced.

Therefore while superficially the challenges faced by the plant seems to result from equipment breakdown, the root cause of these breakdowns is likely to be inadequate cashflow combined with insufficient technical knowledge to ensure a reliable operation. For example, with no funds to repair the squeezer and screen cage, too much fibre is entering the AD system. This has caused mixers and pumps to break.

Similarly, lack of funds has prevented repair of the computer control system and this means that the operators cannot monitor basic operational parameters (such as temperatures and pressures), with a risk that the system will not be operating optimally. Meanwhile the breakage of some of the lab instruments makes it difficult to analyse the moisture content and composition of the gas that feeds the engines, with the result that the engines have been under-performing and may possibly have been experiencing high moisture and H_2S input.

In summary, financial constraints have hampered proper maintenance and repair, with knock-on effects for the performance and viability of the system. The limited valorisation of the outputs, neither heat nor fertilizer are valorised, and limited income from electricity sales have strongly contributed to the cash-flow constraint.

From a technical perspective, it would be interesting to explore lower cost biogas technology that can be replicated in the sisal industry. It would also be interesting to research effective ways of reducing the long fibre content of the feedstock that are within the means of sisal companies to operate and maintain.

Acknowledgements

We are indebted to a number of staff at Katani Ltd. for contributing to a successful visit. The Managing Director Salum Shante kindly gave permission for us to tour the plant and Gilead Kissaka, General Manager of Mkonge Energy Systems, agreed to host us on our proposed visit date. He was unavoidably detained in western Tanzania so Francis Nkuba (Executive Director) and Mr Magogo (Planning Manager) kindly stepped in from the company's Tanga office and gave up their time to accompany us to the site, provide a wealth of information and share lunch with us afterwards. We were guided round the facility by George Kasese and Elisha Cheti. We are grateful to all of these gentlemen for their welcome and kind support.

This report has not been fact-checked by Katani Ltd. and the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
6th June 2017

Case Study AD11: Sucropower Biogas Plant, Thorny Park, KwaZulu-Natal, South Africa

Technology	Anaerobic digestion + heat and power generation
Project developer	Planning & Cost Engineering Services, for Sucropower
Location	Thorny Park farm nr. Mandini, KwaZulu-Natal
Type of digester	Ibert complete mix industrial digester
Year of commissioning	Under construction
Primary feedstock	Napier fodder grass. Possibly sugar cane tops.
Engine size	18 kW_e plus 32 kW_{th}
Contact persons	Nic Bennett, Director, Sucropower Errol Watt, Director, Sucropower
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	22nd May 2017

Project details

Sucropower aims to pilot renewable energy solutions suitable for agribusiness, with a focus on the sugar industry of KwaZulu-Natal. With 55% co-financing from the Energy and Environment Partnership (EEP) programme funded by the governments of the UK, Finland and Austria, the company initiated a joint venture with a local community in the Glendale Valley to convert sugar cane field residues to energy using a biogas system. When the community was unable to raise it share of the funds due to a drought and its effects on sugar cane income, the project developers were obliged to look for an alternative location.

They identified a site on a private farm known as Thorny Park on the south bank of the Tugela river near Mandini. The business model evolved as it become clear that sugar cane wastes would not be available for at least four months of the year (mid-December to April) due to crop seasonality. An alternative feedstock was proposed in the form of Napier Grass, a second-grade fodder crop. A trial plot was planted with Napier at Thorny Park and the pilot biogas installation designed to use this feedstock was nearing completion at the time of the visit. The site itself was locked but the basic configuration could be viewed through the boundary fence and the two Sucropower Directors were on hand to provide information.

The project's EPC contractor is the South African company Ibert, using locally-built, bolt-together steel digesters and a Chinese dual-fuel engine with output of 18 kW_e and 32 kW_{th}. Ibert will train a site operator and technician, and can then monitor the installation from its head office in Johannesburg. Ibert is on a five year maintenance and service contract to ensure that the plant will operate as specified. This will cost Sucropower ZAR 11,500 (USD 900) per month, with a performance-based bonus to Ibert of up to ZAR 5,000 (USD 390).

The business model has evolved to suit the different needs of the Thorny Park site. The Sucropower Directors now see the plant as a prototype multi-purpose energy hub which – if successful – could be replicated at a nearby 'green village' development on another part of the Thorny Park estate. At Glendale they had initially envisaged that heat, power and cooking fuel could be supplied to local people. The adjusted business model at Thorny Park is based largely on the gas upgrading element. With anticipated daily production of 349 m^3, they expect to feed 149 m^3 to the engine and to bottle the balance of 200 m^3 as vehicle fuel. Some 1,300 trucks and buses are reportedly fuelled with landfill gas in Gauteng, and Sucropower believe that if 635,000 m^3 of gas could be produced per year from theirs and other plants in KwaZulu-Natal, then such technology could be attracted to the Province. The challenge they are facing is to locate affordable gas upgrading equipment. A water scrubbing unit is reportedly available via Ibert from EnGas (UK) for ZAR 1.4 M (USD 110,000) that can process 10 m^3/hr of gas, but cheaper options are being sought.

A second envisaged income stream will come from the sale of the CO_2 that will be produced during the gas upgrading process. It can potentially be sold to Afrox for dry ice or as a food grade ingredient.

Further income is foreseen from selling the digestate as fertilizer, for which an offer of ZAR 210-250 per tonne has already been secured (based on 5% nitrogen content).

There is no immediate plan to use the heat from the engine and exhaust, although a block of farm worker housing close by would benefit from hot water supply. In the longer term, the Thorny Park landowner plans to build an essential oil plant 200 m from the AD unit, which would require significant quantities of heat for distillation purposes.

Total project cost is around ZAR 7.2 M (USD 0.55 M), of which the equipment accounts for around ZAR 4 M (USD 0.3 M) and the balance is for permits, planning, land, engineering and management.

Photos

	
First digester tank	**Second digester tank with interconnector (engine room behind)**

Barriers and opportunities for replication

The Sucropower plant and the use of Ibert technology is interesting in several respects. The small scale of the installation – at just 18 kW_e for an investment of ZAR 4 M – makes it potentially replicable for small applications across Africa. The simple bolt-together tank design is relatively cheap and easy to build, and with the engine housed in a shipping container, the whole installation can be delivered in modular form on one or two trucks and installed in two weeks.

It is clear that the business model will depend for its success on multiple revenue streams. Electricity has particularly low value in South Africa as grid power is so cheap, so the project developers are appropriately focussing on higher value outputs such as upgraded biogas, CO_2 and fertilizer.

Securing sufficient feedstock will clearly be challenging, and in particular making a commercial case for the growing of Napier grass on land that could otherwise be planted with sugar cane. Sugarcane may offer better value, given the larger number of by-products. The properties of both the feedstock and the digestate are also not yet well understood, potentially offering an area of useful research. There is also a need to identify a cheap and effective technology for upgrading the biogas, given the high cost of off-the-shelf technology from the UK.

Acknowledgements

We would like to thank Nic Bennett and Errol Watt of Sucropower for taking the time to meet us at the Thorny Park site, and for explaining the thinking behind the project and the various plans to make it a viable pilot for local farms and businesses. This report has been fact-checked by Sucropower, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
4th July 2017

Case Study AD12: Renen Biogas Plant, Sunshine Seedlings, Pietermaritzburg, South Africa

Technology	Anaerobic digestion with heat + power generation
Project developer	Renen Renewable Energy Solutions
Location	Sunshine Seedlings farm, nr. Pietermaritzburg
Type of digester	Induced Blanket Reactor (IBR)
Year of commissioning	2017 (under construction during visit)
Primary feedstocks	Cattle feedlot manure and silage from plant nursery
Engine size	50 kW_e /110 kW_{th}
Contact person	Mike Smith Warren Confait
Email **Tel.**	*Contact authors if required*
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	22nd May 2017

Project details

Renen Renewable Energy Solutions is a South African company that is installing a biogas plant at the Sunshine Seedlings farm, located 15 km north-east of Pietermaritzburg in KwaZulu-Natal Province. Sunshine Seedlings produces 60 million tree, vegetable and flower seedlings per year for the forestry and horticulture industries. The farm will provide fresh organic matter and silage from nursery waste to the biogas plant, although the primary feedstock will be manure from a nearby beef feedlot.

The project incorporates Africa's first Induced Blanket Reactor (IBR) and was financed 35% by Renen and 65% by the Energy and Environment Partnership (EEP) for east and southern Africa, which is in turn funded by the governments of the UK, Austria and Finland. It is being implemented through a Special Purpose Vehicle called Midlands Biogas and Fertiliser (Pty) Ltd, which is own 50/50 by Renen and Sunshine Seedlings.

The plant was under construction at the time of the visit but is expected to:

- generate enriched organic fertilizer for the adjacent farm and external customers.
- generate power for sale to the farm, which has a baseload of 55 kW;
- supply heat for root zone heating in the farm nursery; and
- supply pre-heated water seasonally (3-4 months/yr) to the boiler at the farm's essential oil plant, to reduce demand for heavy fuel oil.

All four primary markets are therefore right on site. The biogas reactor has a substrate feeding capacity of 20 t/day and the majority of the feedstock will come from a nearby cattle feedlot, topped up with around 5 t/day from the seedling and horticultural operation.

The unique aspect of the Renen plant is the use of modified IBR technology. Rather than using a cylindrical reactor as commonly seen in such plants in the USA, Renen is using two up-ended modified 40 ft shipping containers. The aim is to use readily available components that can be easily sourced and repaired, facilitating replication.

The feedstock is first brought into a receiving tank (a sunken shipping container) and pumped from there via a 2-stage mixer and grinder into two buffer tanks that are large enough to hold ten days of feedstock input (to cater for fluctuating supply, rather than to act as hydrolysis tanks). The substrate will be continuously pumped from these tanks into a pre-heating unit located in a free-standing container. A 20 kW Swedish pellet boiler will be used for start-up until gas production is sufficient to power this system and then it will be fuelled with a combination of direct solar panels and 7-10% of the biogas that is generated.. From there the material will enter the main vertical digester at a rate of 1 t per hour. The maximum dry matter content is 11% with a maximum fibre length of 25 mm, while the organic dry matter content (or volatile solids) is 9%. This gives an organic loading rate of 90 kg of volatile solids per m^3 per day for the entire system (without considering material recirculation). This figure seems very high, but may reflect short retention time.

The two up-ended shipping containers have been reinforced with external steel bars to withstand the pressures exerted by the digestate. The tanks are interconnected in two places to allow material to flow between them. They will essentially operate as a single tank. Mixing will take place based on convection initiated by rising gas bubbles created at the bottom.

The retention time is five days at an optimal temperature of 35.2 C (±0.5 C) and pH of 6.5. The digester has a total volume of 20 m^3. Daily gas production is expected to be 500 m^3, based on the feedstock composition described above and organic loading rate of 9%. The quality of gas produced will be constantly monitored. It is

expected to include CH_4 (65%) and CO_2 (34%), which will be partly removed using a confidential scrubbing technology. It will also contain up to 800 ppm of H_2S and this will be partly removed using a microbial scrubber. The biogas will be stored in a 490m^3 bladder tank as buffer for one day's production before being channelled to a plate cooler to reduce its temperature to 3-4 C for injection to a 50kW$_e$/110kW$_{th}$ gas engine. H_2S will be monitored before gas enters the engine, as will moisture, with occasional full spectrum testing of both the gas and digestate. The parasitic load of the system was described as minimal, with only one motor in the main digester tank to break up air bubbles.

A thermophilic reaction takes place at 67 C in the composter, to destroy all pathogens. The sanitised digestate will be pumped into a locally-built screw press and the solid fraction will be aerobically composted in a rotating drum composter to produce enriched organic fertilizer at a moisture content of 40-60% for sale to Sunshine Seedlings. This is subject to registration of the fertilizer as a saleable product and creating a market for it[25]. Trials will also be run with Sunshine Seedlings with the intention of using the liquid portion to 'dose' their irrigation system.

The capital cost of the plant was ZAR 3.2-3.5 M (USD 0.24-0.26 M), equivalent to around USD 5,000 per kW$_e$ of installed capacity. The total cost increases to around ZAR 5.5 M (USD 0.41 M) once civil works, R&D, licensing and EEP's oversight costs are included. Renen aims at payback within five years. Operational costs are USD 800/month for rent, consumables and shared supervision, while electricity is sold at 9.3 US cents kWh$_e$, heat at 4.8 US cents/kWh$_{th}$ and compost probably at USD 0.50/kg.

Renen's Operations Manager is a South African-trained engineer who has visited seven IBR plants in the USA and personally designed the modified IBR unit. The system will be operated on a daily basis by two technicians. They will have only basic qualifications as the aim is to have the plant automated and monitored from Renen's head office.

[25] The compost/fertilizer can only be sold once it has been authenticated in South Africa, which can be a lengthy process. Sunshine Seedlings is nevertheless confident in its value, so in the interim is covering various costs associated with supply of the feedstock.

Photos

Two buffer tanks

Reactor tanks being installed

Site view

Heat exchanger powered by pellet boiler

Picture taken in mid-July
(reactors now upright; solar panels for pre-heating in foreground)

Barriers and opportunities for replication

Renen's Induced Blanket Reactor is still under construction so it is too early to draw firm conclusions on replicability. The use of standard shipping containers and other

locally available components, while reducing the retention time to five days, certainly makes this technology easily replicable in theory, but functionality and commercial viability still needs to be demonstrated.

As with any AD plant, replication will be determined by the availability of sufficient concentrated feedstock, on-site demand for outputs (electricity, heat and fertilizer) and the development of an attractive business model. It was not clear during the visit whether feedstock supply from the off-site cattle feedlot will be reliable, and whether the material from Sunshine Seedlings will be of sufficient quantity and quality for stable biogas production. The technical skills of the operator in handling a variety of feedstocks could not be evaluated and might represent a potential barrier to successful operation, especially as the IBR concept is not yet proven using rectangular digester tanks. Only once technically and commercially proven will it be realistic to create bankable spin-off projects.

Given the fact that this Africa's first IBR system and probably the first globally to use shipping containers as digester tanks, many opportunities for further research exist. These include researching the characteristics of the digestate further to optimise the composting process and to maximise the value of the digestate. Once the plant has been successfully demonstrated at this site, it would be valuable to demonstrate the concept in other parts of Africa and test locally available feedstocks for their suitability in an IBR plant. Researching the ideal business model that valorises heat, electricity, fertilizer and possibly sulphur, and identifying sites with suitable feedstock availability, represents an important area for investigation. Analysing microbiological desulphurisation to produce marketable sulphur represents another potential opportunity for research.

Acknowledgements

We are indebted to both Mike Smith and Warren Confait for their open welcome and detailed tour of the Renen plant. We appreciate their commitment to making the Induced Blanket Reactor a commercial success in South Africa and the wider African continent, and it was kind of them to share lessons learnt and next steps.

This report has been fact-checked by Renen Renewable Energy Solutions, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
25th July 2017

Annex D Case Study Reports: Gasification

The following Case Studies are included in this Annex:

Case Study G1: Novis GmbH Gasification Plant, Kalom, Senegal

Technology	Gasification
Project developer	Novis GmbH
Technology Provider	Ankur Scientific
Location	Kalom, Diourbel Region, Senegal
Type of gasifier	Down-draft
Year of commissioning	2012
Primary feedstocks	Mainly peanut shells. Sorghum stalks have also been tested.
Engine size	29 kW_e
Contact person	Mawulolo Amouzou Glikpa
Email	*Contact authors if required*
Tel.	
Visit conducted by	Ralph Ripken, E4tech
Date of visit	20th June 2017

Project details

The Novis GmbH gasification mini-grid project is located 150 km east of Dakar in the village of Kalom in Senegal's Diourbel Region. It is the smaller (33 kW_e) of two gasification projects developed in Senegal by Novis and was developed in 2012 with funding from Deutsche Entwicklungsgesellschaft (DEG) and Stadtwerke Mainz AG, a German regional power utility. A 'mini-industrial zone' was envisaged in which a cooperative-run peanut de-sheller would provide the anchor load for the gasifier and up to 50 households would also be connected.

Site selection and project description

Kalom is located a few kilometres from a main road where there is unreliable grid power. The village itself has no grid connection but electricity is required for de-hulling of peanuts, the dominant local cash crop. It was this local demand for power and the potential availability of peanut shells as feedstock – together with personal connections – that led to the selection of Kalom as the site for the gasification plant.

The project was developed by Novis GmbH using an Ankur Scientific downdraft gasifier (Gas-32/Combo 50) and a Prakash 29 kW_e net output gas engine (re-designed diesel engine), both from India. The electricity is stored in 24 (2V, 1220 Ah)

batteries controlled by three 5 kW SMA Sunny Island inverters and fed into a local mini-grid with underground cabling. The Ankur gasifier was selected for its reported reliability and was installed by Indian engineers over ten days.

The closest source of peanut shells is reportedly a processing factory 25 km from Kalom, with two additional factories 50-60 km away. Two thirds of the shells came from these factories while the system was working, with the balance from local smallholders. There were no contracts in place to guarantee supply, and the factory increased its price significantly once the Kalom plant started buying its 'waste'.

The gasifier operated from June 2012 to January 2014 and produced 8,327 kWh of useful power (after allowing for 4 kW_e internal consumption). This corresponds to 290 operational hours assuming the plant ran at full capacity. A 2014 technical report suggests that the plant was usually operated for 4 hours about once per week, consuming 200 kg of peanut shells per session - thus implying feedstock consumption of 1.95 kg per kWh of electricity. The shells had moisture content of <20% and were used without any pre-processing, even though a mill and pelleting machine had been provided to make them more homogenous and easier to gasify. Sorghum stalks were also tried but they blocked the gasifier so were not used again.

Recorded power consumption in the village was only 11 kWh per day in 2014, significantly less than the rated capacity of the system (with a possible output of around 116 kWh from a 4 hour session[26]). Although the 'mini-industrial zone' was expected to provide the anchor load, in fact households consumed most of the power produced (6,281 kWh vs. 19 kWh for the mini-industrial zone). Losses in the storage system and mini-grid averaged 24%, according to the report.

Partly due to unreliable electricity supply and the novelty of making payments for electricity, households often paid late or not at all. Given also the lack of demand from the industrial zone and the rising price of feedstock, the project ran out of funds and was stopped in early 2014. Given that the people of Kalom still needed power, Stadtwerke Mainz returned to finance a 20 kW_e solar PV mini-grid with two additional inverters, which has operated since June 2016. Electricity production from the solar system was 15,183 kWh up to June 2017, corresponding to a capacity factor of 8.7%. Electricity is stored in the battery banks, supply is reliable and households are reported to be paying regularly.

[26] Generator capacity 33 kWe minus internal electricity consumption 4 kWe. Maximum available output in 4 hrs = 4 x 29 kWe = 116 kWh.

Business model/economics

Stadtwerke Mainz and DEG financed the gasifier capital costs of EUR 450,000 (USD 500,000) and Stadtwerke Mainz also paid monthly staff salaries of around USD 1,900[27]. Feedstock costs for peanut shells were reportedly XOF[28] 25/kg (4.2 US cents), much higher than the pre-installation planning figure of XOF 1-2/kg (0.15-0.30 US cents). Maintenance and spare parts cost USD 330/month.

Electricity meters were installed in each home but stopped operating. Payments were thereafter based on the number of electrical devices in each household and their capacity, e.g. XOF 2,840 was paid by a household with an installed capacity of 50 W using an estimated 5.6 kWh per month, translating to a price per kWh of XOF 507 (USD 0.86). With average reported electricity consumption of 11 kWh/day for the whole system in 2014, potential weekly income for the project would have been XOF 39,000 (USD 67). If collected, this would have been sufficient to cover the likely weekly feedstock cost of XOF 5,000 (USD 8.50)[29]. A local administrator was collecting the money and the mayor reportedly disconnected households in case of non-payment. This system continues with the solar system.

Process description

The gasifier and auxiliary equipment is started using a 7.5 kVA diesel generator. Peanut shells are fed manually to the reactor via a feed cone at the top. A lid normally remains open, even though air intake could be controlled more precisely via two side openings. The peanut shells fall downwards and a vibration motor towards the bottom of the reactor helps their smooth flow. The bottom of the reactor is a concrete cone which creates high temperatures to crack tars. This element broke during the last operational period. Another motor at the bottom ensures constant agitation. The reactor temperature is normally 500-600^{o}C, but can reportedly reach 1,000^{o}C. Char is recovered from the bottom and used as fertilizer.

Syngas from the reactor enters a venturi scrubber, where water removes tar and particulate matter. The scrubber is cleaned weekly, based on a maintenance schedule that includes other parts of the gasification unit. Waste water from the venturi scrubbers is pumped into a concrete-lined waste water pond. Ideally the water should be treated with a flocculant and the flocced down tar then mixed with shells and burned again. It was unclear, however, whether this was ever done in practice.

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[27] Project engineer (EUR 1,000), three technicians (XOF 75.000 each), manager (XOF 120,000), accountant and guard (XOF 50,000 each), while the plant was operating.

[28] XOF = CFA Franc.

[29] Assumed average operating time 4 hrs every 6 days. 200 kg consumed in 4 h period at XOF 25/day.

For further tar and particulate matter removal, the syngas then passes through two sawdust filters, one sand/gravel filter and an emergency filter with a cloth bag. The sawdust inside the filters was fully coated in tar and particulate matter at the time of the visit. During the operational period the sawdust was reportedly changed every three months.

Prior to the engine, a handle allows for manual gas intake and a dry blower creates sufficient suction to draw the syngas through the cleaning system. Heat from the engine is currently not used.

Measurement

Operating pressure is measured at two points in the reactor and temperature is measured towards the top. The composition and moisture content of the gas entering the engine is not known, however. There is a particular risk of dust and tar contamination if the engine cools down after shutdown. One solution could be to run the engine for a few minutes on diesel after shutting down the gasifier.

The gasifier was usually operated by Mawulolo Amouzou Glikpa, a German-trained Togolese engineer, together with three local technicians. Mr Glikpa's skill ensured successful operation as long as electricity payments were received. He was trained for on-site for ten days by the Ankur installation team and for 6 months at the other Novis-Ankur plant in Senegal. He also gleaned information from the manufacturer's instruction manual. He trained the local technicians who operated the plant on a daily basis and he came to Kalom himself for an average of 2-3 days per week.

Ankur provided a one year performance guarantee. An initial stock of spare parts for the engine and gasifier was kept in Kalom, but further gasifier spares can only be imported from India.

Photos


7.5kVA Start-up diesel generator


Gasifier feeder unit, hopper and reactor

Peanut shells in feeder

Square box and venturi scrubber

Sequential sawdust filters

Tar and PM-contaminated sawdust

Emergency filter and manual gas injection handle

Dry blower

29 kW_e Prakesh engine

Waste water cement pond

Barriers and opportunities for replication

The gasifier at Kalom is one of several Ankur systems in Africa (an exact number is not publicly available) and it operated for around 400 hours[30] between June 2012 and January 2014. A lack of electricity payment by households, resulting in part from the irregularity of the supply, meant that the plant was shut down in 2014 because cash flow was insufficient to purchase additional feedstock. The price of peanut shells from the main supplier increased due to competitive use for animal feed, and this exacerbated the situation. Low power demand due to the failure of the envisaged mini-industrial zone to develop contributed further to the financial problems, because there were no significant anchor costumers. With just 50 connected households using 11 kWh per day, the gasifier was over-sized at 29 kW_e. While capital recovery was never intended and the intention was only to cover operational costs, feedstock prices, customer demand and willingness to pay did not correspond to the developer's expectations or written commitments that had been secured.

It is not possible to comment conclusively on technological barriers to replication as the plant worked only intermittently for 1.5 years. Indications from the visit point to the following key technical barriers:

- Ankur installations have many small but critical parts, e.g. there is one valve approx. 12 mm diameter which often clogs. The equipment requires specific technical knowledge to know exactly which failure to look for, or it can take weeks to identify an issue.
- The coolers on both the starting engine and the main engine broke and proved unreliable, even during the short operating period.
- Syngas production was unstable and this resulted in generator frequency variations. This was reportedly caused by using non-pelletised feedstocks. Higher gas injection resulted in higher frequencies, risking damage to both the generator and any connected motors. The manual system for controlling syngas injection makes it challenging to control input with precision. Gas storage could potentially stabilize the gas injection to the engine and thus stabilize the frequency, but this was considered too dangerous and expensive by the project developer. The inverter can fortunately accept frequencies in the range 45 to 60 Hz so the impact on battery charging and customer supply was at least minimal.

[30] Assuming operation at full capacity

- Most of the electricity meters stopped working and this made it hard to charge consumers appropriately against actual consumption. Some could have been paying too much; others too little.
- Some means of measuring gas composition and moisture content would have been to monitor the effectiveness of the cleaning processes and could have increased the lifetime of the engine.

Several of these technical barriers could be rectified by adapting the design of the gasification plant by sending suggestions back to Ankur Scientific.

Opportunities for successful replication of a similar community-based gasification system are limited. Such systems require assured availability of sufficient feedstock on-site, at constant price, with reliable anchor costumers and ability to deliver power consistently to ensure satisfied customers who are willing to pay. These conditions are difficult to meet in a community setting, as the gasification project in Kalom has shown. A solar based mini-grid seems to represents a more reliable option and the village residents seem happier to pay for this service.

Acknowledgements

I am greatly indebted to Dr. Thomas Helle for facilitating the visit to Kalom by introducing me to Mawulolo Amouzou Glikpa, and for providing comprehensive information on the site. Mawulolo himself provided significant logistical support and I am grateful to both him and to Senateur Woula Ndiaye for their informative tour of the plant.

This report has been fact-checked by Mawulolo Amouzou Glikpa and Dr. Thomas Helle, but the opinions contained herein are solely those of the DFID-contracted consultant.

Ralph Ripken
4th July 2017

Case Study G2: Kumasi Institute for Tropical Agriculture Gasification Plant, Papasi village, Offinso North District, Ghana

Technology	Gasification
Project developer	Kumasi Institute for Tropical Agriculture with support from USADF Power Africa programme
Technology Provider	All Power Labs, USA
Location	Papasi village, Offinso North District, Ashanti Region
Type of gasifier	'Power Pallet' downdraft
Year of commissioning	2017
Primary feedstocks	Palm kernel shells
Engine size	Plated at 31 kVA (24.8 kW_e)
Contact persons	Samuel Owusu-Takyi Benjamin Boahen
Email **Tel.**	*Contact authors if required*
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	27^{th} June 2017

Project details

The Kumasi Institute for Tropical Agriculture (KITA) successfully applied for a grant of USD 100,000 from the USAID Power Africa programme to set up a plant based on the gasification of biomass to supply power to an off-grid community at Papasi in a rural area of Ashanti Region. The application included associate experts from the Centre for Energy, Environment and Sustainable Development.

The selected gasifier is a compact 'Power Pallet' from the Californian company All Power Labs, which has supplied a number of other US-funded power plants in Sub-Saharan Africa. The entire system, complete with a 3 litre gas engine powering a 31 kVA (24.8 kW_e) generator, is sized conveniently to fit onto a single shipping pallet.

The chosen feedstock is oil palm kernel shell, the residue produced when the kernel is cracked to extract the seed for oil pressing. With separate funding from a local teak company, a palm kernel cracking facility was installed under the same open-sided shelter as the gasifier, comprising a 7.5 kW_e cracking unit, an oil expeller (also

7.5 kW_e) and an oil press (11 kW_e). This was therefore to be an integrated palm oil processing facility where feedstock would be prepared on site and the electricity would power the machinery for extracting the oil. Surplus power was to be fed to a local mini-grid for 400 households and street lighting in Papasi village. It is noteworthy that the three oil processing machines could not be operated simultaneously as the total load would be 26 kW_e, higher than the gasifier's generator capacity.

All Power Labs sent a technician to Ghana who spent two periods of three days on site in February 2017 to get the equipment working and to train five people from the project team in gasifier operation. A community committee was set up to run the project and its members selected a primary-educated technician (who was also trained).

All Power Labs manufactures sophisticated, computer-controlled technology that achieves clean gasification by elevating the reactor temperature to around 950^{o}C. A compact reactor is top-fed by a screw augur that pushes pre-heated material into the chamber, with a control for air intake on the side. A blower draws the syngas through to the engine via a condenser, feedstock pre-heater, heat exchanger (to reduce the temperature) and activated charcoal filter. Exhaust heat from the engine is partially captured for reactor heating. The gasifier does not use water in the cleaning process, avoiding potential problems of waste water cleaning or disposal that are associated with wet cleaning designs.

Technical difficulties were encountered almost immediately after commissioning. It appeared that the blowers designed to help ignition and sustain the gas flow from the reactor to the engine were sized for different feedstock and were not strong enough for the feedstock being used at Papasi, despite claims on the All Power Labs website that palm kernel shell has been "tested and approved with increased operating effort"[31]. This led to difficulties igniting the material in the reactor as sufficient through-draft could not be established. Once lit, the kernel shells exuded acidic oil that was drawn through the system and began to corrode the blower impeller blades. The main blower soon broke and a replacement had to be ordered from the USA. Intrusion of an unidentified oil/tar mixture to the engine was also observed, and suggests chemical properties of the feedstock than the system could not cope with. It seems probable that the impaired ability of the fan to draw gas through the system resulted in sub-optimal reactor temperature leading to higher tar and particulate matter levels, perhaps exacerbating the oil/tar problem.

[31] www.allpowerlabs.com/wp-content/uploads/2015/10/PP20GeneratorOneSheet10_25_15Small.pdf

Although the oil-damaged blower fan had been replaced by the time of the visit, the machine had not been put back into service because the fan was still under-sized and incapable of drawing gas through the system with the required strength. The feed augur had also been damaged by the feedstock. The system is mothballed for the time being, awaiting a solution including a stronger blower and stronger augur[32].

Power was supplied free of charge to the local community for a 4 hours per day for a few weeks when the gasifier was initially functioning. Total operating time has been only 56.3 hours over the four months since February 2017, however. The palm kernel processing equipment has not been used at all. There is an established community-run oil processing facility only 200 metres away using a diesel-powered oil press which looked busy.

Photos


Palm kernel cracker


Palm kernel (original, cracked and seed)


All Power Labs gasifier
(engine L, reactor R, feed hopper top)


All Power Labs gasifier
(gas filter L, control panel centre)

[32] A report from KITA after the visit confirmed that it had in fact been relocated to Kumasi for proper investigation.


Engine and electricity generator


Control panel


Gas blowers


Damaged impeller blades

Barriers and opportunities for replication

The Papasi project faces both technical and economic challenges that impede prospects for replication. The performance of the equipment has been disappointing and it has not run satisfactorily with palm kernel shells. This may be due to their high oil content and the way they impede air flow to the in-built blower. Even if the equipment had operated smoothly, the fact that the project is 100% grant-financed with consumers paying nothing for the power raises questions over economic viability. Therefore as a research project the initiative has been a valuable learning opportunity for the project partners, but falls well short of being a functional demonstration of the potential for a gasifier to power an economically sustainable mini-grid.

The All Power Labs gasifier is fully automated and has turned out to be sensitive to feedstock properties out of its design range. It is hard to see how such equipment could be replicated except in a tightly controlled setting using wood chips or pellets as fuel. Replication is further constrained by the absence of a regional support office with a stock of spare parts, meaning that customers can only get assistance from the

USA if equipment breaks. The units comes with a two year warranty, but it seems difficult to enforce given that it has only operated for 56 hours.

Prospects for replication could potentially be enhanced if All Power Labs set up a permanent presence in the region, but fundamentally the equipment seems too complicated for the level of technical capacity typically found in rural Africa and it is hard to envisage circumstances under which it could operate successfully and sustainably for any length of time. Encouraging a well-trained engineer to stay in rural villages, remote from any large town, represents a considerable challenge in itself. The longest-known operating gasifier from this manufacturer was installed at Gulu in Uganda and reportedly ran for 300 hours before breaking down irrecoverably (Pamoja Cleantech, personal communication).

With a simpler and more robust gasifier it is possible that a mini-grid power distribution model might prove workable, provided that all customers were on pre-paid meters and that there was a sizeable anchor load. Biomass-based power could potentially be combined with solar PV to provide 24 hour power. This would need to be set up on a sound commercial footing right from the start, with an assured anchor customer and consumers willing to pay a commercially realistic electricity tariff.

Acknowledgements

We are grateful to Samuel Owusu-Takyi from KITA who kindly accepted our request to visit the gasifier at Papasi, and to Benjamin Boahan from the Centre for Energy, Environment and Sustainable Development for accompanying us to the site and providing a useful and informative tour. Samuel's assistance was also invaluable in securing our visas for Ghana.

This report has been fact-checked by KITA, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
27th July 2017

Case Study G3: Ebonyi State Government Gasification Plant, Ekwashi Community, Ngbo Clan, Ohaukwu Local Govt. Area, Ebonyi State, Nigeria

Technology	Gasification
Project developer	Ebonyi State Government with UNIDO support
Technology Provider	IISc Bangalore, India
Location	UNIDO Industrial Cluster, Ekwashi, nr. Okwor Ngbo Market
Type of gasifier	Downdraft fixed bed
Year of commissioning	2012
Primary feedstocks	Chopped branches (wood)
Engine size	Cummins 32 kW_e (heat not used)
Contact person	Elom Chukwuma, State Coordinator UNIDO Projects
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant
Date of visit	20th June 2017

Project details

The installation of a gasification plant in Nigeria's Ebonyi State can be traced back to a 1999 study by a civil servant in the State Government (Elom Chukwuma) that profiled opportunities for small-scale industrial development. A UNIDO fact-finding mission in 2001 drew upon the report's recommendations to design a programme of support for developing light industry which continues today, with Mr Chukwuma now the permanent Coordinator of UNIDO Projects on behalf of the State Government.

One of the sites visited during the 2001 mission was Okwor Ngbo market, a commercial hub with hundreds of small workshops and crop processing mills. At the time it lacked a grid electricity connection and a 1 MW gasification plant was proposed to provide the necessary power for the light industries to thrive. Budget constraints meant that the unit eventually installed in 2012 was a relatively small 32 kW_e plant at a site 1.2 km north-west of the commercial centre. This was intended to serve as a demonstration 'micro-industrial cluster', with the aim of expanding later depending on results. The plant was fully funded by UNIDO at a cost of USD 27,548. The State Government provided the structure to house the equipment.

The site lies within the jurisdiction of Ngbo Clan and the Clan Leaders Council agreed to form the Ngboejogu Bio Energy Multipurpose Cooperative Society Ltd to manage the project on behalf of the community. The Cooperative Society is meant to provide feedstock, manage the on-site borehole, bill customers for services and handle community relations. The State Government assembled a team of seven support engineers who were trained by UNIDO, three of whom were sent to India for more in-depth training. The State Technical Team is responsible for plant operation and maintenance.

The equipment came from the Indian Institute of Science (IISc Bangalore) and is a fixed bed downdraft gasifier. The reactor is top-fed with wood waste that is chopped on site using an electric circular saw. There is no reliable source of feedstock and the process of chopping each stick is rather labour intensive. From the reactor, a turbo blower draws the syngas through a cyclone, two wet scrubbers, a chiller and a cloth filter before it is fed into a Cummins gas engine at a target temperature of 12^{o}C. Engine exhaust heat can be directed to a wood drying oven if required, where 0.5 t of feedstock can reportedly be dried to 13% moisture content in 30 minutes. The scrubbing water is recirculated and cooled via an external pond, while an adjacent sedimentation tank and stone sand bed filter are designed to remove tars and other contaminants from the water. Due to low operating hours it is not clear if these waste removal systems have been effective. There is no facility for disposing of the contaminated water or tar so it is presumably dumped on open ground nearby.

The system has a simple control board which indicates the gas temperature as it exits the reactor, and a panel of mechanical gauges provides basic pressure information from different points in the gas cleaning and chilling system. Gas temperature during the visit was in the range 145 to 155^{o}C as it entered the cleaning system, which was on the upper side of the target range of 90 to 150^{o}C.

The plant can reportedly produce 1 kWh of electricity with 1.1 kg of dry feedstock. Allowing for internal consumption of around 7 kW_e for pumps and blowers, it can supply about 25 kW_e of available power. The aim had been to operate a 19 kW_e rice mill that was installed in an adjacent structure, but this apparently overloaded the switchboard, despite being well within the stated output range. This resulted in shutdown of the plant for about three years while spares were sourced from India. After repair, the aim was to power a pump to provide the local community with water from the on-site borehole via an overhead tank and a nearby tap-stand. In practice, the plant does not operate with sufficient consistency to provide this service.

Total plant operating time has been only 98 hours since 2012, according to the engine counter, with the Technical Team reporting that the maximum operating run has been about eight hours in a single session. The plant has therefore seen very little service since commissioning. It is worth noting that it was established for

demonstration purposes and the State Government acknowledges that the power generated is insignificant to carry meaningful activities.

The gasifier is simple and robust, and seems quite capable of delivering power and heat in line with manufacturer specifications. There is no revenue generated from sales of power or water, however, so the project continues to rely on the State Government to pay for the Technical Team and for all operation and maintenance. It is located away from the commercial centre and a grid connection has arrived since the plant was installed, albeit an unreliable connection that supplies power only sporadically. The absence of a commercial model inevitably raises questions about the value of the plant as a demonstration facility, besides simply showing that a gasifier can generate electricity from wood waste. It would require a very different operating set-up if it was to be replicated on a sustainable commercial footing, based on private sector investment and profit-oriented management.

Photos

Preparation of feedstock using circular saw

Wood dryer (heated from engine exhaust)

Reactor overview

Feedstock on top of reactor


Cyclone and wet scrubbers


Water cooler and recirculation pond


Gas chiller


Engine

Barriers and opportunities for replication

Replication of the gasifier project would be facilitated simply enough by raising additional public funds to install more units. The State Government would like to replace the existing plant at Ngbo Clan with a 1 MW unit to provide sufficient power for the market centre, given the unreliability of the grid connection and the inability of the 32 kW_e to meet anything more than a small fraction of local demand. Ebonyi State is also a leading rice producer and there are various rice milling centres where the Government wishes to install additional units. Donor funds are being sought to install four 1 MW gasifiers using rice husk and a further five using rice husk and wood waste (one of 1 MW and four of 500 kW). As noted, however, the original project has not demonstrated that it represents a viable economic solution. Grid power, where available, is reportedly quite cheap at about NGN 40/kWh (US 0.12 cents) and no comparison of costs with power from gasification has been developed to demonstrate commercial competitiveness. The State Government nevertheless maintains that acute power shortages and grid unreliability make renewable energy (including power from gasification) the only reliable means of sustaining economic

activities. Based on studies by UNIDO international consultants, it seeks to promote gasification for projects of 500 kW to 1 MW, and steam turbines for plants above 2 MW.

From a technical and operational perspective, feeding of the reactor is labour-intensive and inefficient, with a bag of chopped wood having to be hauled to the top of the structure and poured in every 45 minutes during peak operation. Automation of this process would save on labour and is a design feature that see IISc could consider if feedback was possible. The preparation of feedstock is also laborious and inefficient, despite this being a recommendation of IISc.

Acknowledgements

I am greatly indebted to Elom Chukwuma of the Ebonyi State Government for his warm invitation to visit the State-run gasifier facility at Ngbo Clan, and for assisting with local logistical arrangements on a day when the domestic flights to and from Enugu created a number of last minute problems. The Secretary to the State Government kindly assisted with my Nigerian visa arrangements and the Acting Secretary graciously met me for a short courtesy call during the field visit. Eng. Emmanuel Emeka met me at the airport and drove me to and from the site, and provided helpful background information.

This report has been fact-checked by the Ebonyi State UNIDO Coordinator,, but the opinions contained herein are solely those of the DFID-contracted consultant.

Matthew Owen
18th July 2017

Case Study G4: Pamoja Cleantech Gasification Plant, Ssekanyonyi, Uganda

Technology	Gasification
Project developer	Pamoja Cleantech
Technology provider	Husk Power Systems
Location	Magara village, Ssekanyonyi, Mityana District, Uganda
Type of gasifier	Downdraft fixed bed
Year of commissioning	2012
Primary feedstocks	Whole maize cobs
Engine size	32 kW_e
Contact person	Raymond Lumansi, Technical Manager, Pamoja
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech
Date of visit	16th May 2017

Project details

Pamoja Cleantech is a Swedish social enterprise developing decentralised renewable energy projects in developing countries. Projects are installed in rural communities using agricultural residues or biomass from agroforestry as energy sources, with the aim of empowering local entrepreneurs[33]. Pamoja has developed three gasifier projects in Uganda, one (near Gulu) using an All Power Labs gasifier from the USA and two others (to the west of Kampala) using equipment from Husk Power Systems in India to power local mini-grids. The Gulu installation is no longer operational due to equipment limitations, while the DFID consultants had the opportunity to visit one of the Husk Power systems at Magala village close to Ssekanyonyi in Mityana District, approximately 70 km west of Kampala. Pamoja has recently secured co-financing from the Energy and Environment Partnership (EEP) programme for an additional gasifier at an agri-hub further west in Kamwenge District.

The 32 kW_e Magala project was set up in 2012 with funding from the Nordic Climate Facility via the Renewable Energy Business Incubator at Makerere University, in

[33] www.pamojacleantech.com/about/what_we_do/

cooperation with the Rural Electrification Agency of Uganda. The plant is connected to 75 households via a local 220 V mini-grid. The gasifier was located next to a diesel-powered maize mill, which was expected to switch to electrical power and provide a 10 kW_e anchor load, but the owner did not make this switch so the min-grid has been supplying only households. With an estimated peak demand of less than 100 W_e per connection, peak load is only around 7.5 kW_e. This is well below the gasifier's rated capacity (and also well below its lowest turn down capacity of 40% / 13 kW_e). The grid is therefore not operational at present for economic reasons, though Pamoja kindly organised a demonstration for the consultants' benefit.

The Husk Power unit is a downdraft gasifier fuelled with maize cobs. These are gathered at no cost from local farmers after the two harvesting seasons (January-February and July-September) and kept in storage until properly dry. The plant had originally been operational for 6 or 7 hours each evening to match customer demand, but for the last year or two has been powered up only occasionally as the low demand for power has not justifies regular operation. When operational, 100-125 kg of whole maize cobs were manually fed into the top of the gasifier for each 6-7 hour session, implying 1.5-2 kg/kWh. The unit was probably delivering only 9-12 kW_e, around one third of the installed capacity.

Figure 1 shows the flow of syngas from the reactor to a venturi scrubber, the first stage of the cleaning process, while char is collected at the bottom of the reactor. The reactor does not contain any devices to measure temperature or pressure.

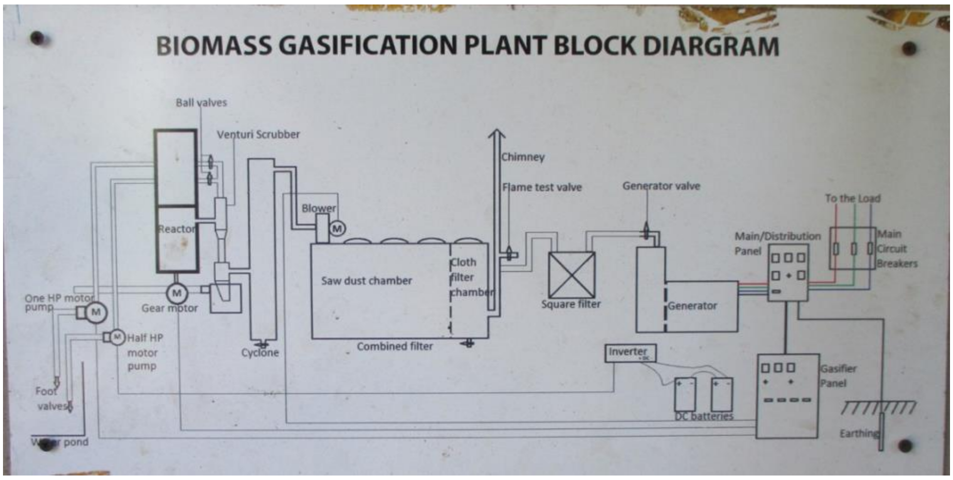

Figure 1. Husk Power Systems biomass gasification diagram at Magala

The scrubber is designed to remove tar and particulate matter. Levels of both contaminants would be rather high with the gasifier running at less than one third of capacity. The scrubbing water is collected in a pond and recycled back to the scrubber once cool. The syngas is then sucked into a cyclone to remove additional particulate matter and then blown into a multi-stage tar filter (with one charcoal filter

and two sawdust filters). A final cloth filter removes remnant tar ahead of a re-purposed diesel engine that produces electricity.

The gasifier reactor does has no temperature sensor but is believed to reach 500-600°C. This is rather low and may mean that the feedstock is being pyrolised rather than gasified, contributing further to high tar content in the syngas. Low reactor temperature could result from a combination of the large size of the (unchopped) maize cobs, an open-topped reactor that allows uncontrolled air ingress, lack of insulation, gasifier operation at low capacity or wet fuel.

The gasifier cost USD 50,000, excluding installation. Operation and maintenance, including staff salaries, was to be covered by electricity sales. Customers were paying for power using pre-paid cards but stopped doing so once supply became intermittent. Staff have instead been paid from Pamoja's own funds. Routine maintenance is undertaken by locally trained operators, while major repairs are supported by a Kampala-based engineer who spend a year on placement with Husk Power Systems in India. The entire system, including the engine, was imported from India so any major spares would also need to be imported.

Photos

Magala project signboard

Gasifier reactor

Maize cob storage

Gas filter box

Cloth filter

Engine

Barriers and opportunities for replication

The Magala gasifier is one of at least ten Husk Power units in East Africa, all of which have either broken down or have seen operations suspended for lack of commercial viability. While technically operational, the system is not economically viable based on the combined power demand of 75 rural households. Pamoja have decided not to keep it running at a loss. The main barrier to replication is finding sites with sufficient demand from anchor costumers. The Husk Power technology also faces challenges reaching a sufficiently high reactor temperature to achieve proper gasification. This may result in part from the use of whole maize cobs, which are probably too large and would be better pre-chopped. It may also result from design limitations as the incoming air supply cannot be controlled and the reactor is not insulated. There are opportunities here for improving the Husk Power technology to raise the reactor temperature and produce cleaner gas.

Acknowledgements

We are indebted to Felix Ertl of Pamjoja Cleantech, who made the connection to Pamoja's Uganda operation and introduced us to the Kampala office. Nicolas Fouassier gave us a warm welcome while Raymond Lumansi provided an informative tour of the gasifier at Magala. We are aware that Pamoja have critically evaluated the Magala experience for themselves and are modifying their approach based on the lessons learned, and we appreciate their openness in sharing the challenges.

This report has not been fact-checked by Pamoja Cleantech and the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
3rd July 2017

Case Study G5: Cummins Co-Generation (Kenya) Ltd. Gasification Plant, Marigat, Kenya

Technology	Gasification + power generation
Project developer	Cummins Cogeneration (Kenya) Ltd.
Location	Marigat, Baringo County, Kenya (0.471962, 35.981800)
Type of Gasifier	Biogen G1300 downdraft gasifier
Year of commissioning	Still in testing phase
Primary feedstocks	*Prosopis juliflora* wood chip
Engine size	2 x 1.2 MW_e
Contact person	John Kamau, Management Accountant
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech Ankit Agarawl, LTS International
Date of visit	11th May 2017

Project details

Cummins Cogeneration (Kenya) Ltd. (a joint venture between Cummins Power Generation and Gentec Energy) has developed a gasification project at Marigat in Baringo County designed to generate electricity for grid feed-in and to showcase advanced gasification and gas engine technology in the African market, while aiding the local economy through purchase of feedstock from local people. The EPC contractor was Gentec (UK) and the project comprises three G1300 downdraft gasifiers from Biogen Corporation (Dominican Republic) and two QSV91 gas engines from Cummins Power Generation (UK). The capital investment to date has reportedly been in the range USD 2-3 million and the site is fully set up and ready to operate, but faces a gas cleaning challenge that has yet to be overcome.

The feedstock to be used is *Prosopis juliflora*, a tree introduced to Kenya from South America in the 1980s as a source of woodfuel, which has become highly invasive and needs to be brought under control. With financial assistance from the African Enterprise Challenge Fund 'REACT' window (Renewable Energy and Adaptation to Climate Change Technologies), Cummins set up a supply chain for Prosopis from six community-based organisations (CBOs) in the Prosopis-invaded area between Lake Baringo and Lake Bogoria. The CBOs will be paid KES 2 (2 US cents) per kg for the

feedstock if moisture content (MC) is between 15-25%, with downward adjustment for wetter material. 36 t/day is reportedly required to keep the two gas engines continuously operational.

The feedstock is trucked to the Marigat site, air-dried to about 12% MC and sized to 5 mm using a chipping unit. The chips are fed into three screw-feeders, one connected to each of the gasifier reactors. The reactor is designed to reach 800-900°C and generates char and ash as by-products. The char is collected beneath and screw-fed from al three units to a common external collection point. Char output is 70 kg/hr per unit. Cummins aims to sell the char to briquetting companies for KES 11 (11 US cents) per kg, though has not done so yet.

Hot gas exiting the reactor passes through a dual cyclone cleaner to remove particulates and then enters two wet scrubbers where it is sprayed with water to further separate ash particles and some tars. The first scrubber reduces the gas temperature from 300 to 85°C and the second drops it to about 50°C. The cooled and partially cleaned gas passes through additional heat exchangers, further reducing the temperature and condensing tar. The system was designed as a closed loop with zero tar production so there was no provision for safe disposal of contaminated water.

The gas is then bubbled through biodiesel in a sparger tank, prior to entering a high voltage electrostatic precipitator (ESP) to remove any remaining particulate matter.

The clean gas is then fed into two storage tanks and from there is blown through a cooler and into the win gas engines. The resulting power is stepped-up and fed into the grid (with a small part used to power the facility). Cummins has signed a Power Purchase Agreement with the Kenya Power and Lighting Company for 10 US cents/kWh. The Cummins engines are each apparently capable of producing 1.75 MW_e but the local grid limits output to 1.2 MW_e per unit.

Despite significant investment in setting up the plant, it is not yet operational due to excessive tar build up in the wet scrubbers. The amount of tar generated was reportedly around 15 l/hr as against a manufacturers' recommended amount of less than 5 l/hr, making it unsuitable to operate the gas engines. The ESP was designed for a certain level of particle removal, but is unable to achieve full gas cleaning at the current level of contamination.

The tar build-up was said by the technicians on site to result from a combination of the chemical properties of the feedstock and high dust levels. The gasifier was apparently trialled successfully with a South American variety of Prosopis, but the African variety is said to have different chemical characteristics. High levels of dust in the feedstock are also said to contribute to the gas cleaning problems. The exact cause remains unclear, however, as the properties of different forms of biomass at

12% MC should not differ so significantly that they render the whole cleaning system ineffective. Tar production is more often an indication of gasification temperature being too low.

The plant had a staff of around 150 technicians, operators and community managers during construction and development of the CBO supply network, but now maintains a skeleton staff of around 16 people, pending development of a solution to the gas cleaning challenges.

Photos

Feedstock (*Prosopis juliflora* chips)

Screw feed hoppers

Gasification system

Control panels

Gas tanks

Engine interior

Biochar

Sub-station

Barriers and opportunities for replication

The Cummins' gasification project at Marigat has been successful in developing a unique community-based feedstock supply, potentially providing employment and income to local people, whist tackling an invasive vegetation problem and generating power to achieve economic sustainability. Despite the backing of an experienced technology developer, however, the project has suffered from the gas cleaning challenge common to many gasification projects. This highlights the need to run adequate pre-testing on the actual feedstock before full investment goes ahead. The GenTec team is still reviewing options to tackle the problem, but the length of time this has taken indicates of the technological complexity of operating gasification plants and the need for further technical research into gas cleaning.

A potential barrier to replication not yet encountered (because the project is still not commissioned) concerns the security of feedstock supply under a community procurement model. The CBOs have no stake in the project and no direct benefits beyond cash sales of Prosopis, which may expose the project to risk of price hikes or supply constraints. The project would benefit from any lessons that can be drawn from other community-based feedstock supply models, to understand how they have ensured the necessary buy-in and commitment to keep the plant operational.

With a PPA tariff of only USD 0.10/kWh and zero heat recovery, the commercial viability of the plant is uncertain. Although the setting of viable feed-in-tariffs to support the bioenergy industry is a matter of government policy, opportunities to improve system efficiency by recovering as much energy as possible lie with the developer. In the Marigat plant, the waste heat could potentially be used for pre-drying the feedstock and this could in turn can help reduce the dust problem that is exacerbated by open drying. A simple blower could be retrofitted to direct exhaust heat through an open-sided container containing the raw material.

Acknowledgements

We are indebted to John Kamau for his open welcome and informative tour of the Marigat gasification facility. We would also like to thank his colleagues on site

(Nicodemus Mutua, Jemima Jerop and Silas Tisgol) for taking us through each step of the process and for answering our many questions. This report has been fact-checked by John Kamau, but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen, Ralph Ripken and Ankit Agarwal
6th July 2017

Case Study G6: Kilombero Plantations Gasification Plant, Mngeta, Morogoro, Tanzania

Technology	Gasification
Project developer	Kilombero Plantations Ltd.
Technology Provider	Fengyu Corporation, China
Location	Mngeta, Morogoro Region, Tanzania
Type of gasifier	Bubbling fluidized bed
Year of commissioning	2015
Primary feedstocks	Rice husk
Engine size	500 kW_e (heat not used). Zibo Zichai brand.
Contact person	John Kiragu, Power Manager
Email	*Contact authors if required*
Tel.	
Visit conducted by	Matthew Owen, LTS International consultant Ralph Ripken, E4tech Peter James, AgDevCo
Date of visit	16th May 2017

Project details

Kilombero Plantations Limited (KPL), located 450 km south-west of Dar es Salaam in Morogoro Region, is Tanzania's largest rice producer with almost 6,000 ha under irrigated and rain-fed production at its Mngeta estate. KPL is also now alternating maize with rice each growing season. KPL is majority-owned by Agrica (98%), itself mostly owned by Pacific Sequoia (62%) and Norfund (31%). AgDevCo, a UK government-backed social impact investor in agriculture, is also negotiating a potential equity investment in Agrica and, in the meantime, provides debt financing to both Agrica and KPL.

The area under irrigation has expanded from 215 ha in 2013 to 2,995 ha in 2017, with the aim of increasing peak yields to 7 t/ha of paddy rice and 12 t/ha of maize per crop. The irrigation pumps and pivots require up to 1.7 MW_e during the dry season and the expanding irrigation system has increased peak demand for the whole operation to 3.0 MW_e, although this peak is theoretical and routine consumption is substantially lower. Annual power demand is around 471 MWh. Rising electricity demand was one of the drivers for the installation of a bioenergy power plant in

2015. Other power sources include a 320 kW_e hydroelectric plant and two 400 kW_e Caterpillar diesel generators.

KPL commissioned a feasibility study that identified gasification as a cheaper and more efficient bioenergy option than steam turbines for small scale operation (<6 MW). A technical investigation in 2012 led to the selection of a 500 kW_e Chinese dual-fuel engine and a Fengyu atmospheric bubbling fluidised bed gasifier with a rated output of 1,500 m^3/hr using rice husk[34]. After an Environmental Impact Assessment by TRES Consult in 2014 and the with approval of the KPL Board, the plant was imported and installed by Chinese contractors and commissioned by the South African company Energy 1 W2E (Pty) Ltd. The plant started operating in 2015, but besides a four week continuous run in the commissioning stage, has been run only intermittently for a total of about 50 days (based on the engine counter). The estate was connected to the national grid in 2016 and this has affected the rationale for the gasifier investment, given that KPL pays a relatively low tariff for grid power that averages US 12.2 cents/kWh[35].

The gasifier is fed with paddy rice husk from the milling process, which has a moisture content of around 12%. Operational data from July 2015 suggest husk demand of 2.4 kg/kWh of power generated[36], or about 17 t per day under continuous operation.

The husk is also in demand for fuelling the KPL's large rice drying operation. Two small husk furnaces supplying heat to silo driers each require 250kg/hr of husk, while a large Louisiana State University (LSU) drier furnace consumes a further 2 t/hr. At present there is insufficient husk to fuel both the rice dryers and the gasifier, due to a reduction in output resulting from the inter-cropping with maize, as well as recent poor harvests. KPL intends to use more chopped rice straw and maize stalk in the LSU furnace in future, to make more rice husk available for the gasifier.

The rice husk is stored in an open-sided shelter from which it is hopper-fed into the gasifier reactor. The reactor is insulated with a clay lining and operates at 700-800^{o}C, according to in-built temperature sensors, somewhat lower than the 950^{o}C indicated in the EIA but nevertheless within the normal operating range for a BFB system. Air is blown upwards via internal nozzles. The feedstock must be manually agitated to avoid blocking of these nozzles using two stirring rods attached to the reactor door.

[34] The rated output seems optimistic, as 1,000 m^3/hr would usually be more realistic for this raw material.

[35] According to KPL's Deputy Managing Director, the power price varies depending on the mix of kWh & maximum demand in kVa. The utility (TANESCO) calculates maximum demand for each month based on the highest for the quarter. The blended rate based on consumption plus charges plus irrecoverable VAT was about US 12.2 cents/kWh for financial year 2016/17.

[36] At a test run on 10th July 2015, 17,160 kg of rice husk was used to generate 7,104 kWh of power.

Discussions have taken place with Energy 1 W2E about automating this process. The gas from the top of the gasifier passes through two cyclones linked to downpipes for ash removal. Based on an operational report for June 2015, 16.8 m^3 of ash is produced for every 24 hours of operation, representing 13.3% of husk intake by weight.

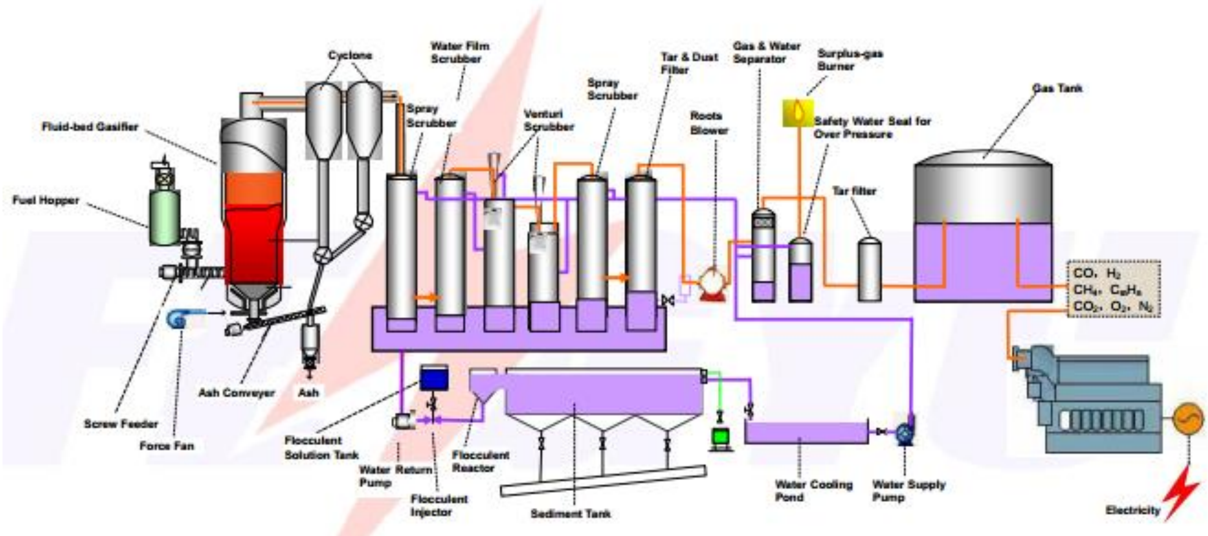

Figure 2. Flow chart of the Fengyu gasification process

After the cyclones, the gas passes through a series of six wet scrubbers to remove ash, particulates and tar. These also cool the gas from around 750 to 40°C. The scrubbing water circulates between a tank immediately below the scrubber columns and a separate sediment tank, in which particulates sink to the bottom and tar floats on top. This scrubbing water needs to be mixed with a biodegrading agent[37] and drained every two weeks to collect the dust and tar particulates. The use of the agent would in principle allow the plant to operate for up to a month. 200 hours between maintenance breaks is apparently the norm in South Africa and Swaziland.

It was not clear where the effluent gets discharged and this could represent an environmental hazard as the tar contains toxic hydrocarbons. Trials have been undertaken on using the tar on field roads. When in full continuous operation with bacterial digestion, KPL has been assured that residual tar would be much lower than during short operating runs. Effluent water could be usable in field operations, though analysis to confirm this has not been carried out. Another solution to the disposal problem would be to evaporate most of the water and burn the tar in the boiler.

[37] The agent is an aggressive enzyme and bacteria-based product called Micromix that comprises 0.2% organic nitrogen, 3.5% organic carbon, 1.5% potassium (K_2O), 1% phosphorous pentoxide (P_2O_5), 31% sorbitan monolaurate (ethoxylated), 25% enzyme and microbial blend, and 6.3% water.

Suction through the scrubbers and cyclones is created by a 30 kW_e root blower. After the scrubbers, the gas passes through a gas and water alkaline separator that removes alkalides that are not fully combustible using sodium hydroxide. Two tar catchers then reduce tar and moisture still further, the first using steel sieves and the second using rice husk, before an electrostatic precipitator extracts the remaining particulate matter. The tar-contaminated rice husk is dumped nearby.

While gas temperature and pressure are measured at different points during the cleaning process, the composition and moisture content of the gas entering the engine is not known. There is a particular risk of dust and tar contamination as the engine cools after shutting down the gasifier. One solution could be to run the engine for a few minutes on diesel after shutdown.

The syngas is stored in a 5m^3 floating dome storage tank and fed to a 500 kW_e Zibo Zichai New Energy Co. dual-fuel re-purposed diesel engine. Neither the heat from the exhaust gases nor engine cooling are currently used, though using exhaust heat and (more interestingly) flare-off gases has been discussed in principle as a possible heat source for the silo dryers.

The gasifier is operated by KPL's Power Manager (an electrical engineer) together with a biomass technician who previously worked at the forestry company TimSales in Kenya, where a similar Fengyu gasifier was installed. Modifications to the cyclones and ash take-out have been made on-site. The KPL team has received support from Energy 1 W2E, which operates plants at forestry operations in South Africa and Swaziland, though the KPL staff themselves lack specific technical training in gasification and would require a service engineer from China for any major repairs. There is no performance guarantee or warranty support. Spare parts for the gasifier and engine can only be imported from China.

Photos

Rice husk storage

Rice husk feed hopper

Reactor and ash removal

Manual agitator for bottom of gasifier

Cyclones & ash removal system

Wet scrubbers

Tar catchers

500kW$_e$ engine

Barriers and opportunities for replication

The gasifier at Kilombero is one of three Fengyu gasifiers in Africa and the largest on the continent that uses rice husk. The project feasibility study suggests that there is a business case for gasification using agricultural wastes if no grid connection exists and the energy demand is seasonal and in line with raw material supply (rice husk in

this case). The gasifier has operated only intermittently, however, due mainly to insufficient feedstock because of competing demands for rice drying.

A number of potential solutions are being explored. The gasifier could be fuelled with chopped maize cobs to gain more operating time, for example, though KPL's preference is to substitute risk husk demand elsewhere, as the gasifier is quite sensitive to feedstock variability. Tests may also be carried out on blending sawdust with rice husk. Using the exhaust and engine heat for rice drying could also partially reduce the feedstock challenge, though adapting the engine to a CHP unit would require an investment of perhaps 30% of the engine cost.

Given the delicate balance between supply and demand for raw material for both the drying and gasifying operations, it would be useful to have a well-structured measurement system that tracks the actual feedstock volumes required. This would help optimize the finite feedstock supplies between the various uses and assist with quantifying current and future capital expenditure decisions. To achieve this would require additional records to be kept on maintenance, labour, asset useful life, etc applicable to the plant.

It is not possible to comment conclusively on technological barriers to replication as the plant has been working only intermittently. Indications from the visit suggest that the following improvements could be beneficial:

- Automatic agitation at the bottom of the gasifier to avoid blocking of the air nozzles would be preferable to manual agitation, which is tiring for the operators and performed inconsistently. This change has already been made on at least one Fengyu plant in South Africa.
- The configuration of the pipes for removing ash from the cyclones proved inappropriate and they frequently became blocked with ash. They had to be modified by removing inspection hatches and junctions to reduce friction. As cyclones are effective at a specific rated gas speed, it is possible that the gas was not exiting the reactor at the designed velocity. The first cyclone should also usually be bigger than the second one (to remove larger particulates first), whereas the KPL cyclones appear to be equally sized. Some modification to diameters, angles and configuration may be appropriate.
- Some means of measuring gas composition and moisture content would be helpful in determining the effectiveness of the cleaning processes, though it is also important that the plant should perform in accordance with manufacturer guarantees, and gas monitoring would not be necessary if that was the case.
- Establishing a local equipment dealer would ensure availability of spares and service engineers, rather than relying on technicians from South Africa or China.

Given the limited plant operational time, it is too early to evaluate whether the gasifier at Kilombero represents a successful model for replication at other agricultural or agro-industrial sites in Africa. The arrival of the grid connection in 2016 has probably undermined the commercial case and it seems likely that this type of technology is best suited to captive energy use in off-grid locations. Assured feedstock supply is necessary, with seasonal availability that corresponds appropriately with peak power demand. Applications for heat (as well as power) would make a stronger business case.

Acknowledgements

We are indebted to Peter James of AgDevCo for facilitating our visit to KPL, to David Arnott (KPL Deputy Managing Director) for kindly authorising the visit and providing significant logistical support, and to John Kiragu and Tom Mukanda for their informative tour of the gasifier plant.

This report has been fact-checked by KPL but the opinions contained herein are solely those of the DFID-contracted consultants.

Matthew Owen and Ralph Ripken
20th June 2017

Annex E Steam turbine techno-economic research

Objective

During the previous phase of the BSEAA study, combustion-based steam turbines were not taken forward for Case Study analysis owing to the lack of operational examples at a micro- to small-scale in SSA. With DFID's endorsement, this free-standing piece of research was conducted to analyse small-scale steam turbine technology more closely on the basis of technological efficiency and economic competitiveness, in comparison with available alternatives. The aim was to provide a better understanding of the challenges facing adoption of steam turbines at a sub-1 MW scale, and to indicate areas of potentially useful research based on the findings.

Technical Analysis

Combustion-based steam turbines have been an industry standard for large scale power generation for decades. They are a mature technology with favourable capital costs at large scales (>5 MW), requiring minimal maintenance during the first five years of operation and much more tolerant of feedstock variability (e.g. moisture content, calorific value) than gas engine/turbine alternatives. Despite the existence of various manufacturers offering compact steam turbine systems from as low as 50 kW, however, (as showcased in the TVC Prioritisation Report to DFID), their practical application at low output levels has been limited. In order to investigate why this might be the case, the efficiency of steam turbines compared with other technology options at different scales was explored. Efficiency was analysed in the following scale ranges, using a classification adapted from Junca, et al (2014):

i) Micro scale (<50 kW_e)
ii) Small scale (50 kW_e to 1 MW_e)
iii) Large scale (>1 MW_e)

Large-scale power generation is not within the scope of this study. Table 5 summarizes the efficiency characteristics of steam turbines in relation to other technology options at micro- to small-scale. Efficiency estimates are given for both power-only and combined heat and power (CHP) configurations, to highlight the efficiency gain that can be achieved if thermal output is also captured.

Table 5. Typical efficiency ranges of micro- to small-scale CHP technologies (Energy and Environmental Analysis, Inc, 2015; OPET Network, 2003; Junca, et al., 2014; Dong, et al., 2010)

Scale	Technology	Electrical efficiency (%) ($MJ_e/MJ_{biomass}$)	CHP efficiency (%) ($MJ_{[e+th]}/MJ_{biomass}$)
Micro	Steam turbine	6-8	>60
	Internal combustion engine	13-25	60-74
	Organic Rankine Cycle	7.5-13.5	60-80
	Stirling engine	9.2-33	65-92
	Micro turbine[38]	12.3-26	62-73
Small	Steam turbine	6-8 (500 kW_e)	70-80 (500 kW_e)
	Internal combustion engine	12.5-28	75-95
	Organic Rankine Cycle	7.5-23	56-90
	Stirling engine	12-35	85-90
	Micro turbine	25-33	62-89

Steam turbines are clearly much less efficient than the alternatives for the production of electricity alone at sub-1 MW scales, though only marginally less competitive in CHP configurations.

From an efficiency point of view, turbine performance is linked to the following process factors, among others: i) steam inlet pressure; ii) inlet temperature; and iii) turbine exhaust pressure/vacuum. Maintaining optimum values of these parameters improves turbine efficiency by reducing steam consumption (Vankayala, n.d.). For instance, when turbines operate or exhaust at low pressure, air can leak into the system resulting in power output below expectations and a need to treat the makeup water to avoid boiler and turbine material problems. On the other hand, increasing steam inlet pressure increases efficiency by raising the system's saturation temperature, thus increasing the average temperature of heat added to the cycle. But higher inlet pressure and temperature confer penalties in terms of safety, requiring the use of more expensive materials to reduce blade corrosion and damage, thicker turbine casing, advanced control systems and other process features such as more sophisticated boilers. Sophisticated boilers include several stages of steam heating which in turn means several regions of carefully controlled combustion in the boiler chamber, the costs of which (together with the other costs mentioned) increase as system size reduces, making high input pressure a less attractive option at small scales (Energy and Environmental Analysis, Inc, 2015; Dong, et al., 2010). Furthermore, condensing-only steam turbines typically exhaust to sub-atmospheric

[38] Microturbines are essentially low-power versions of traditional gas turbines used in large power plants. Typical power outputs range from a few tens to a few hundred kW. Natural gas is the most common fuel for microturbines, but bio-fuels are also increasingly used.

pressures to enable the extraction of maximum enthalpy, which is quite reasonable in a larger system but challenging to achieve cost-effectively in smaller systems.

Table 5 meanwhile shows that Stirling engines provide good performance with outputs of a few kW_e (1 to 50 kW_e), especially under the CHP configuration, due to high thermal output (Junca, et al., 2014; Obernberger & Thek, 2008).

The following two graphs are adapted from a review by Junca, et al (2014) which compiled efficiency data for both electricity and CHP production from close to 50 CHP plants in different regions of the world. The very high combined efficiency (117%) of Organic Rankine Cycle (ORC) plants (Figure 4) results from the addition of flue-gas condensation to cool the working fluid below its dew point. With this process, heat from the atmospheric air can be recovered, thus enhancing the efficiency to values greater than 100% because the efficiency is calculated in relation to energy input from biomass, not including the energy stored within the atmospheric air in the form of heat (Junca, et al., 2014).

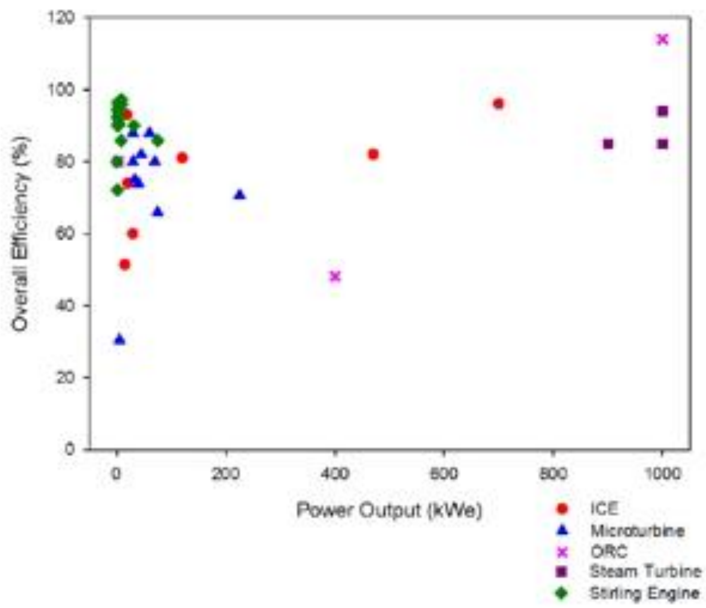

Figure 3: Electrical efficiencies of biomass conversion technologies (Junca, et al., 2014)

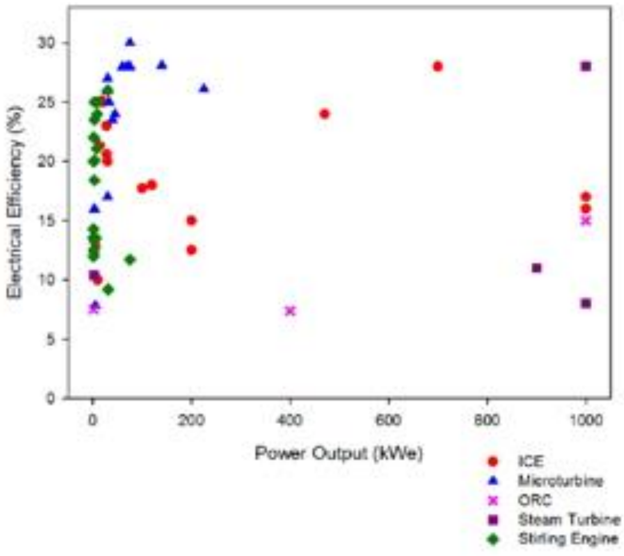

Figure 4 Total efficiencies of biomass conversion technologies (Junca, et al., 2014)

The graphs show there has been minimal global deployment of steam turbine technology for CHP generation at micro to small scale in comparison with other technologies.

Micro-turbines are much more widely adopted for electric outputs of few kW_e to about 250 kWe. Due to the use of air cycles, such turbines do not face the challenges caused by condensation of the working fluid that are faced in steam cycle turbines. This reduces the need for a sophisticated boiler to reach the desired temperature and pressure conditions. Micro-turbine configurations also make it possible to do recuperated cycles (at least more easily than for large machines), which offsets some of the efficiency losses caused by the small scale. Due to promising benefits over conventional gas turbines (fewer moving parts, no lubricant or coolant requirements, better step-load characteristics and lower CO_2 emissions (Greenwalt, 2015)), the microturbine market is slowly growing as concerns about emissions and environmental regulations rise.

As the scale of electricity generation increases, these technologies are surpassed by ICEs and ORCs, which show the greatest efficiencies for electricity generation between 50 kW_e and 1 MW_e (Junca, et al., 2014). ORCs, operating on a variant of conventional steam turbine cycles, are becoming particularly popular because the organic working fluids have favourable thermodynamic and fluid mechanical characteristics that lead to high turbine efficiency under partial load and load-changing conditions. These fluids have lower latent heats of vaporisation than water, and can operate at a lower temperature and pressure, a key advantage that make ORCs attractive. So, while a lower temperature still means a lower maximum (Carnot) efficiency than can be achieved, it allows the opportunity to pick a refrigerant that suits specific circumstances. Furthermore, the operating costs are low since the ORC

process is closed. Maintenance costs are also low since the vapour can expand in the turbine in both saturated and super-heated states, avoiding blade erosion; and a high potential for automation further contributes to the appeal of ORC (Obernberger & Thek, 2008; Dong, et al., 2010). Although ORCs are now commercially available from 400 kW_e to 1.5 MW_e in developed markets, greater R&D money has been spent on upscaling the technology over the past decade (Dong, et al., 2010). As a result, despite the higher electrical efficiencies of ORCs than steam turbines, the investment cost compared to steam turbines for small-scale applications is still high. This is probably why ORCs have yet to achieve major commercial success.

In summary, the poor electrical efficiency of small-scale, low-pressure steam turbines is a major deterrent to their uptake and newer improved systems such as Stirling engines and ORCs are seeing greater uptake in micro- to small-scale applications.

Economic Analysis

Despite the higher technological maturity and lower cost of steam turbines compared with other available technologies, their uptake in SSA has been negligible.

The following analysis study estimates the costs of retrofitting a steam turbine to an existing boiler unit, and determines how the cost per unit of electricity generated compares with grid electricity costs. The analysis is based on the additional investment cost of a CHP plant compared to a conventional biomass combustion plant with a hot water boiler and the same thermal output. It takes into account the additional O&M costs of running the turbine and generator.

It is important to bear in mind that this is not only an economic decision. Such an integration is not simple and existing boiler and steam conditions would need to be carefully analysed to ensure the steam cycle is workable. Specifications such as mass flow, pressure, temperature and backpressure or extraction conditions must be carefully customized to the existing boiler specifications (Energy and Environmental Analysis, Inc, 2015).

In a favourable situation where it is possible to customize the existing steam conditions for a steam turbine, the investment decision is based on the additional capital and operating costs of the steam turbine, given that the other components (e.g. fuel conversion system (boiler), fuel handling and preparation machinery, condenser, cooling tower (if applicable) prep yard, building and site, labour, process controls) are already in place. The operating parameters of the existing plant, such as the feedstock quantity and costs, local labour rates, existing machinery O&M, etc, are assumed to be similar and are therefore not considered.

The costs of steam turbine equipment vary greatly depending on size, inlet and exit steam conditions, turbine rotational speed and standardisation of construction. There

are additional costs associated with the generator, controls and electrical interconnection, as well as new infrastructure or improvements that may be required (such as heat transfer/recovery systems and emission reduction hardware). In fact the steam-turbine generator costs generally make up only 10-15% of total plant costs (Hawkins, 2017; Energy and Environmental Analysis, Inc, 2007; US Dept. of Energy, 2016). Cost estimates range from USD 1,140 to 4,200/kW_e for a 500 kW_e retrofitted steam turbine system (Energy and Environmental Analysis, Inc, 2015; IRENA, 2012), (US Dept. of Energy, 2016; Obernberger & Thek, 2008).

Given that the Levelised Cost of Electricity (LCOE) is highly sensitive to the investment costs, a band of potential LCOE values was calculated to indicate how this range compares with current electricity prices in the ten priority SSA countries chosen for BSEAA. Operation and maintenance costs are usually estimated as a percentage of the capital investment in USD/kW (Energy and Environmental Analysis, Inc, 2015) or on the basis of the annual energy production (USD/kWh) (US Dept. of Energy, 2016; Bios Bioenergiesysteme GmbH, 2014). The latter is more common, and an estimated USD 10/MWh_e is assumed for this analysis. An 80-90% capacity factor is typically applied for CHP steam turbine plants having a constant feedstock supply (IRENA, 2012; Energy and Environmental Analysis, Inc, 2007). Given the vagaries of feedstock security in an SSA context, the lower estimate of 80% capacity factor is assumed. While the discount rate for biomass-based projects in developed countries ranges from 9-13% in developed contexts (Oxera Consulting, 2011), a discount rate of 20% is used in this analysis, reflecting the higher risks in developing countries.

Taking the above factors into consideration, Figure 5 below compares the range of calculated LCOE values for a 500 kW_e steam turbine to grid electricity costs in the ten priority countries. Electricity costs are based on official tariffs from national utility websites (apart from Ethiopia). A range is presented in those cases where different tariff rates apply for power generation capacities ranging from 200 kVA to 1,000 kVA.

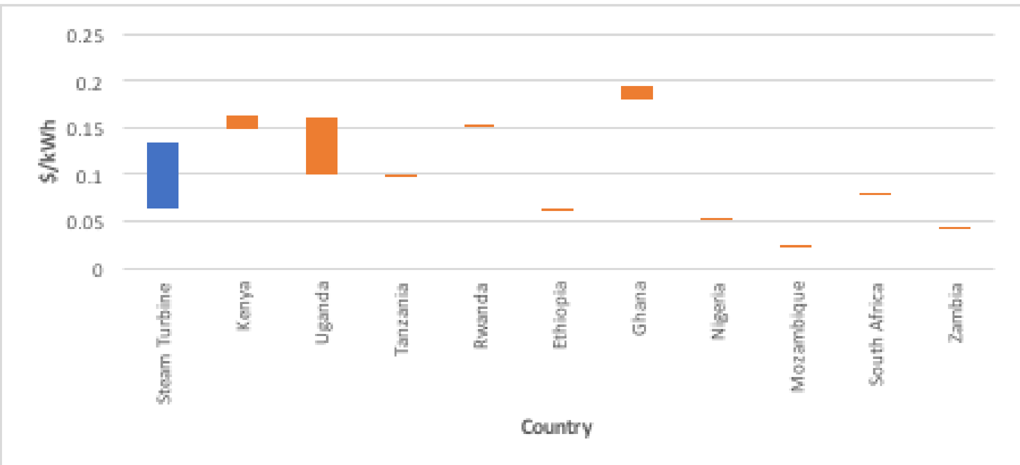

Figure 5: Comparison of steam turbine LCOE with electricity tariffs of ten priority SSA countries

Figure 5 demonstrates the cost competitiveness of retrofitting a steam turbine to a biomass-based boiler, compared to using grid electricity. On the basis of the current electricity tariffs, the ten countries can be categorized into three bands of investment potential (Table 6).

Table 6. Investability potential of steam turbine retrofit to biomass-based boiler

High	Medium	Low
Ghana Kenya Rwanda	Uganda South Africa Tanzania	Mozambique Ethiopia Nigeria Zambia

The economic case for steam turbines looks poor in low potential SSA countries such as Ethiopia, Mozambique, Zambia and Nigeria, where current electricity tariffs are below USD 0.061/kWh, lower than even the most optimistic cost estimate for steam turbine CHP generation. Meanwhile there seems to be a strong economic case in Ghana, Kenya and Rwanda, where electricity tariffs are higher than the conservative LCOE estimates of USD 0.133 /kWh. In medium potential countries such as Uganda, South Africa and Tanzania, where electricity prices fall within the estimated LCOE range (USD 0.063 to 0.133/kWh), the economic case will depend heavily on the electricity and heat demand, the condition of the existing boiler and steam system, and on more robust cost estimates of the turbine technology, funding mechanism and associated interest rates, and overall risk.

This economic analysis reveals that combustion-based steam turbines are potentially competitive for CHP production in countries where electricity tariffs are high and the steam turbine unit can replace all or most of the power supplied from the grid. The potential is strong particularly for small breweries, sugar and palm oil mills in Kenya, South Africa and Nigeria, for instance, where there is an existing steam application on site. A real world example developed by Dresser-Rand, Siemens demonstrates that there is economic potential for applying steam turbines in certain instances. Siemens retrofitted a 200 kW_e steam turbine to a brewery in South Africa with an existing steam application on site. The electricity was to be used internally and the overall cost of system integration was USD 250,000 with a payback of three years (Hawkins, 2017), an attractive investor scenario.

An end-to-end CHP installation (including the boiler and associated equipment) at small to medium scale can have a payback of up to 15 years, for which most private investors don’t have the risk appetite. If additional internal and external factors such as use of diesel generators, transmission and distribution inefficiencies, and carbon offsets are taken into account, however, the economic case for steam turbines is strengthened. Given that this is currently not the case across all countries and

potential end-users are limited, the potential for replicating steam turbines across SSA is poor.

Conclusion and recommendations

This techno-economic study has analysed the potential for combustion-based steam turbines in terms of both technical efficiency (in comparison to other thermo-chemical pathways at the same scale) and economic potential based on retrofitting a steam turbine to an existing boiler/steam generation system. The study has confirmed the poor technical efficiency of steam turbines in comparison to available alternatives. Different areas of technical research are ongoing, such as improved combustion systems for boilers, heat transfer and aerodynamics to improve turbine blade life and performance, and improved materials to permit longer life and higher operating temperatures for more efficient systems (Energy and Environmental Analysis, Inc, 2015). These research areas may offer marginal improvements to the performance of small-scale turbine plants.

The economic analysis reveals some opportunities and suggests value in supporting feasibility assessments of retrofitting applications. DFID-supported research could potentially be directed towards techno-economic studies and possibly low-cost finance to agri-businesses which have both a functioning heat generation system and also a significant electricity demand. The analysis suggests that such research would be most appropriate in high potential countries such as Ghana, Kenya and Rwanda, where the cost of electricity for industrial use seems to be higher than the upper estimates of LCOE of steam turbines.

A practical challenge faced by developers operating in SSA is that system integration is often a problem since biomass boilers and steam turbine generator manufacturers are disjointed and may give very conflicting system requirements for the same desired power output (Hawkins, 2017 ; Amadi, 2017). There is therefore a need and an opportunity for DFID to create an enabling environment to attract such turnkey solution providers to supply this service.

Note: We would like to thank Jonathan Hawkins (Dresser-Rand, Siemens) for kindly sharing his insightful industry experience on some of the challenges and opportunities of combustion based steam turbines in SSA.

Bibliography

Amadi, A., 2017. *Combustion based steam turbines, email exchange* [Interview] (12 July 2017).

Bios Bioenergiesysteme GmbH, 2014. *Techno Economic Evaluation of selected decentralized CHP applications based on biomass combustion with steam turbines and ORC processes,* Graz: International Energy Agency.

Dong, L., Liu, H. & Riffat, S., 2010. Development of Small-Scale and Micro-Scale Biomass-Fuelled CHP Systems. A literature review. *Applied Thermal Engineering,* Issue 29, pp. 11-12.

Energy and Environmental Analysis, Inc, 2007. *Biomass CHP Catalog: Section 7-Representative Biomass CHP System Cost and Performance Profiles,* s.l.: US EPA Combined Heat and Power Partnership.

Energy and Environmental Analysis, Inc, 2015. *Catalog of CHP Technologies: Section 4. Technology Characterization – Steam Turbines,* s.l.: US EPA Combined Heat and Power Partnership.

Greenwalt, M., 2015. *Using Microturbines to Turn Waste Gas into Energy.* [Online]
Available at: http://www.waste360.com/gas-energy/using-microturbines-turn-waste-gas-energy
[Accessed 17 March 2017].

Hawkins, J., 2017. *Lessons Sharing from Industry. Dresser Rand, Siemens* [Interview] (13 July 2017).

IRENA, 2012. *Renewable energy technologies: cost analysis series,* s.l.: IRENA.

Junca, A. G., Riba, J.-R., Puig, R. & Navarro, P., 2014. Review of micro- and small-scale technologies to produce electricity and heat from Mediterranean forests ' wood chips. *Renewable and Sustainable Energy Reviews,* Issue 43.

Kotchen, M. J., 2010. *Cost-Benefit Analysis; Encyclopedia of climate and weather, 2nd edn.,* Oxford: Oxford University Press.

Obernberger & Thek, G., 2008. *Combustion and Gasification of Solid Biomass for heat and power production in Europe: State-of-the-Art and relevant future developments.* Vilamoura, 8th European Conference on Industrial Furnaces and Boilers.

OPET Network, 2003. *Micro and small-scale CHP from biomass (< 300 kWe) for distributed energy,* Helsinki: OPET Finland.

Oxera Consulting, 2011. *Discount rates for low-carbon and renewable generation technologies,* s.l.: Committee on Climate Change.

US Dept. of Energy, 2016. *Combined Heat and Power Technology Fact Sheet Series,* Washington, DC: US Dept of Energy.

Vankayala, S., n.d. *Improve Steam Turbine Efficiency Understand the factors that affect steam consumption.* [Online]
Available at:
http://www.academia.edu/6881335/Improve_Steam_Turbine_Efficiency_Understand_the_factors_that_affect_steam_consumption
[Accessed 12 June 2017].