ENERGY CATALYST

Technical Guide: Bioenergy

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Bioenergy refers to all energy derived from biological sources, and includes biomass fuels. Worldwide, it is the largest single source of renewable energy. In some developing countries, the share of bioenergy in the primary energy supply can be as high as 90%. Bioenergy is an essential energy option for a wide-range of applications, and it will remain an important source of energy, particularly in developing countries, for the foreseeable future.

Nevertheless, the current utilisation of bio-energy in Africa is predominantly unsustainable and inefficient. About 65% of Africans, primarily in rural areas, rely on traditional biomass for cooking. Bioenergy use for cooking has increased health problems and mortality rates as a result of the indoor air pollution that it causes. However, there is huge potential for deploying modern, efficient biomass fuels and technologies.

Modern biomass technologies, such as biogas and improved cooking stoves, could be used as substitutes for traditional cooking stoves in the household sector. Biogas could also be used for power generation and transport. Bioenergy, in the form of bio-ethanol and biodiesel, could serve as a substitute for petroleum products in the transport sector. The diverse benefits of bioenergy may include reduced greenhouse gas emissions, creation of rural livelihoods, reduced deforestation, improved indoor air quality and reduced dependence on imported sources of energy.

Bioenergy can be classified in two main categories: “traditional” and “modern”. Traditional bioenergy typically refers to the combustion of biomass, like wood, animal waste and traditional charcoal. Modern bioenergy technologies include liquid biofuels produced from bagasse and other plants, bio-refineries, biogas produced through anaerobic digestion, and wood pellet heating systems.

Bioenergy is the conversion of a feedstock by a conversion technology into a final energy use (visualised by the figure below). This guide will focus on the different types of feedstock and available conversion technologies. In most cases, the final energy use will be electricity and/or heat.

Feedstock

Feedstock is the biomass source used as fuel for the conversion technology.

Wood fuels

Wood fuel is the single most important primary energy source across the African continent. Wood fuel is primarily used for cooking and heating in the residential sector, though sizable amounts are also used by small and medium size industries for metal processing, food processing and brick making. Wood is used either directly as firewood or in the form of charcoal. It is estimated that about one fifth of harvested wood fuel is converted to charcoal.

Typically, fuelwood for cooking is used in rural areas and collected rather than harvested. Charcoal is a main driver for deforestation and primarily an urban fuel. Given high levels of urbanisation and low social and economic barriers for its use, charcoal consumption is expected to rise.

The use of wood fuels in households is associated with indoor air pollution and resulting respiratory diseases, when particulate matter and carbon monoxide (CO) are released during combustion. A separate commercialisation guide looks into improved cooking methods as replacements for the traditional three stone fire, which can reduce the level of indoor air pollution as well as the amount of fuel needed.

For use in industries, increased efficiency and more sustainable harvesting of wood fuels are areas of attention that could offer opportunities for emerging industries. In particular, the sustainable harvesting of otherwise unused wood resources like encroacher bush can offer business opportunities.

In addition to sustainable management of natural and planted forest, fast-growing wood fuel plantations can provide feedstock for modern bioenergy production. IRENA estimates the wood supply potential from forests (beyond what is needed for non-energy purposes) in Africa at around 1.85 EJ/yr. About 35% of this potential is situated in East Africa and a further 31% in West Africa. There are already 11 wood based power plants, with a total installed capacity of almost 30 MW, operating in Ghana, Congo, Ethiopia, Tanzania, Namibia and Eswatini, and a number of new plants are planned or under construction.

Biomass residues

Biomass residues are unavoidable by-products of agricultural and forestry processes. They typically include:

- Wood logging residue, the parts of trees that are left in the forest after removal of industrial wood and wood fuel
- Crop harvesting residues generated in the fields, such as wheat straw, maize stover, cassava stalk, etc
- Residues generated on animal farms, which may include manure and a mixture of manure and bedding materials
- Agro processing residues generated at the agri-food processing plants, for example rice husks, sugarcane bagasse, etc
- Wood processing residues generated in sawmills, furniture production facilities, or similar, which include bark, sawmill dust, and cuttings
- Biodegradable waste, including the organic fraction of municipal waste, construction and demolition debris, etc

The total supply potential of crop harvesting and agro-processing residue in Africa is estimated at around 4.2 EJ in 2030.

As collection and transportation of residues tend to have a significant cost, it is most cost-effective to convert feedstocks into fuels or final energy forms as close as possible to the point of creation of these residues. Situations where the owner of the residues is the one running the bio energy conversion facility are most favourable, as no contracts and agreements need to be drawn up with the owners of the residue. Typically, the asking price for these waste residues tends to go up as soon as there the realisation is had that the bioenergy producer will need them to run the conversion processes. In some cases, the waste and residues may have negative environmental impacts like the need for storage space, emission of decomposition gasses (typically methane), or other pollution of the environment. As a result, the bioenergy technologies provide a cost-effective solution for their treatment in addition to energy production.

Crop-harvesting residue can be used as feedstock for briquettes and pellets. Briquettes have been successfully marketed as an alternative to wood and charcoal in a number of countries in Africa and Asia.

Their greater density means reduced transport costs, a longer burning time and, depending on the type of biomass and processing method, fewer emissions. However, many briquetting projects have failed in the past due to poor project planning, marketing, low quality products and lack of availability of appropriate stoves.

African countries possess substantial sugarcane industries that could also be a significant source of sustainable heat, power and biofuels. Substantial potential exists to scale up the sustainable production of bioenergy from sugarcane cultivation in a number of countries in the region.

In a study by SACREEE covering seven countries in southern Africa, it was concluded that if yields were improved and all the sugarcane surplus to sugar requirements were converted to bioenergy, some 1.4 billion litres of ethanol could be produced at an average cost of USD 0.71 per litre of gasoline equivalent, all within the 554 000 hectares of land where sugarcane is already cultivated in the seven countries studied.

Traditionally, the combustion facilities at sugar mills were designed to take the bulk of the available bagasse (a waste product from sugar processing) and convert it into steam and electricity for the processing plant. With more and more governments in Africa and Asia opening up for IPPs that supply to the national electricity grid, there is a good business case for optimising the electricity generation process. This can be done internally by the sugar factory or outsourced to an energy service provider. It should be noted, however, that not all IPP tariffs offered by governments are high enough to make it economically viable. At the same time, more and more countries are looking at blending bio fuels like ethanol with petrol to lower the carbon footprint of vehicular energy use.

Besides bagasse, there are several other biomass by-products that are typically generated in Africa which have energy value. For example, wood processing and logging residues in Africa could provide sufficient feedstock for up to 20 GW of power generation capacity.

In addition to power generation, biomass residues are suitable for a range of industrial applications, providing process heat, as well as heating and cooling of industrial facilities. Using biomass fuelled boilers process heat can be produced for industries like dairy, baking and beer brewing.

Conversion technology

Conversion technology conveys the process used to convert biomass into a useable form of energy. Typically, this will be another energy carrier like biogas or briquettes which may be used for heat for cooking or industrial processes, and/or electricity for own use, or feeding into a localised mini grid or the national electricity grid.

Anaerobic Digestion

A biodigester is a closed, airtight vessel in which organic material (typically animal manure or agricultural waste) is degraded by bacteria in the absence of oxygen, converting it into methane and carbon dioxide. Biodigesters also produce liquid fertilizers, which can be used on plants and other crops. The slurry from the digester is rich in organic matter, ammonium, and other nutrients. The slurry can be used directly as compost and is a potent organic fertilizer contributing to sustainable land management. Biodigester technologies range from simple plastic bags on beds of straw to produce small amounts of gas for cooking, to complex systems such as Upflow Anaerobic Sludge Blanket (UASB) digesters used in farming installations capable of producing several megawatts of electricity. Biodigesters have multiple co-benefits, including: waste disposal of organic material so that animal waste, human waste, or other organic materials (from agricultural waste, slaughterhouses, etc) do not contaminate groundwater; emissions reductions from digestion of manure and offsetting methane from the natural decomposition of the feedstock; and emissions reduction by substituting renewable energy for fossil fuels.

Domestic or farm level digesters

Biogas is commonly used in rural areas of China and India, mainly for cooking. Uptake in Africa is lower but has increased over the last decade, with most systems installed at the domestic level. The estimated potential for biogas in Africa is significant, with 18.5 million households having sufficient dung and water, primarily in rural areas.

Figure 1 Biodigester by (B)energy, Source: BBOXX.

Several types of biodigesters are available. Traditional brick dome digesters have been promoted for several decades and have seen incremental improvements. They are generally reliable but require specific skills in their construction to avoid defects such as cracking over time. Depending on the country, these fixed biodigesters may also carry a higher cost than other, more temporary digesters. A good example of a low-cost solution is the “Plastic Bag Digester,” an inexpensive, prefabricated plastic biodigester designed for farmers in developing countries, also commonly known as tubular plastic digesters. The device, which is UV-resistant, can be manufactured locally and installed in one day.

Another model was distributed throughout Tanzania and Kenya by the company SimGas, which introduced small-scale, environmentally sustainable, manure-fed biodigesters and stove systems custom-designed for the East African farmer.

Despite the significant reported benefits of small-scale biodigesters, biodigesters have relatively low penetration in Sub-Saharan Africa. Cultural aversions arise to using manure linked to cooking and logistical challenges with transporting manure as feedstock. However, with agriculture employing half of the labour force in Africa, and small farms employing 175 million people directly, biodigesters create a good option for cleaner cooking within targeted farming demographics across Sub-Saharan Africa.

Functionality of biodigesters is a key challenge. The lack of well-trained and motivated technical staff for the reliable construction of fixed dome digesters, farmer training, after-sale services and quality assurance are barriers for achieving a sustainable, market-oriented sector. Furthermore, the type of digester promoted should be carefully considered. Capacity building and training should be provided for farmers, masons, biogas companies, and agricultural extension staff.

High costs of installation and maintenance can deter interest in biodigesters. A clear value proposition must be presented to farmers for the technology to be attractive. Agriculture programmes could address this through strong rural extension programmes, to provide training and awareness and to facilitate access to finance and provision of capacity building to (micro-) finance institutions and farmers. Innovative financing mechanisms need to be supported, such as the use of existing agriculture structures (such as cooperatives and Savings and Credit Cooperative Organisations (SACCOs)) for the provision of microfinance or lease-to-own facilities.

A general lack of demand and awareness of the existence and benefits of biodigesters is a key barrier. The two key products of biodigesters – biogas (gas for clean cooking and lighting) and slurry (fertilizer) – need to be highlighted when communicating with farmers and other stakeholders. These products bring a variety of benefits, including agricultural yield increases, reduction of cost for agricultural inputs, workload reduction (primarily for women), improved health due to cleaner cooking fuel, increased rural employment, and decreased deforestation.

Insufficient government support can hinder private biogas sector development. The absence of guiding policies and a supportive regulatory framework creates uncertainties and can discourage private investment in the biogas sector. Government support can contribute to awareness about biodigesters and the benefits for crop cultivation, while regulation, enforcement of standards, and provision of licenses can support sector development and create the trust needed among end users for stable demand growth.

Figure 2 Anaerobic digester by HomeBiogas, Source: BBOXX.

Recently, a number of innovative projects have surfaced that offer domestic biogas on a Pay-as-You-Go principle. The main characteristic of solar PV PAYG, the ability to remotely shut down the system in case of non-payment, was something technology providers have been struggling with for the biodigester technology. BBOXX has started a pilot in East Africa in which customers will get a biodigester, cookstove and smart valve that allows them to pay-as-they-cook. The company deploys an innovative Smart Valve to monitor biogas production, payments and usage. This is integrated with a cloud-based reporting and management platform. For this pilot, BBOXX has teamed up with Homebiogas, which has experience with small-scale biodigesters across several countries including Rwanda and Kenya and offers a well-developed product.

Table 1 Summary of barriers for household/farm level bio digesters

Type	Description
Financial	• Installation costs for conventional biogas systems are unaffordable for many potential users with limited or no disposable income • Lack of flexible credit schemes and other financial support for potential biogas users and entrepreneurs to setup biogas businesses • Competition from firewood where wood collection is free and available
Technical	• Lack of local system performance documentation • Poor design and construction due to a lack of local capacity • Lack of technical skills (especially in rural regions) and inadequate training and follow-up • Lack of water supplies or permanent water supplies • Reliance on expensive imported construction materials and spare parts • Insufficient feedstock and/or time and money
Sociocultural	• Preference of cooking the traditional way with firewood stoves • Inertia towards change and new technology • Competition with traditional/other uses of feedstock materials such as cow dung • Social/cultural/religious objections to using animal or human waste • Rearing of cattle and other livestock carried out in open fields/animals allowed to wander, making dung collection for biogas unfeasible • Biogas technology adoption may require a change in the traditional energy use decisions: women and children are most likely to use the biogas system while men are most likely to make investment decisions • Low literacy levels make adoption of the technology more difficult • Lack of awareness about the technology and its benefits
Institutional	• Insufficient government support or biogas policies • Low population density • Ownership and responsibility of biogas system not well defined/understood • Lack of up to date information, knowledge sharing, and translational biogas research at national, continental, and international scales

Commercial digesters

Feedstocks for large-scale biogas plants originate from a wide range of activities and industries, such as sewage, food waste, crop waste, livestock waste, municipal solid waste (MSW), agricultural waste and agro-processing residue. Several studies point to a high potential for these resources globally and in many developing countries, with most of the resources directly correlating with increased population and industrial expansion. The use of some of these resources as biogas feedstock engenders multiple benefits. Biogas technologies can assist in improving the environmental management of solid and liquid waste from municipal and agro-processing facilities.

Figure 3 Commercial anaerobic digester using cow manure and industrial waste, Source: Bio2Watt Bronkhorstspruit plant South Africa.

Commercial biogas installations can generate electricity, either for on-site use, feeding into the national grid or wheeling to third party users, as well as heat that can be used as process heat for industries. Potential target users of large-scale biogas technology in Africa could be crop and livestock farmers, small-to-medium and large food processing industries, wastewater management organisations and municipalities, and solid waste management municipalities.

Barriers to increased uptake of commercial biodigesters are similar as for any renewable energy technologies, related to high upfront costs, unconducive regulatory and legal frameworks and difficulties related to securing PPAs to feed into the grid. However, anaerobic digestion is facing a number of additional, technology-specific barriers like difficulty of securing feedstock, the general absence of proper waste management and absence of the cost associated with dumping potentially suitable feedstock, unclear environmental legislative frameworks that might classify digestate as a hazardous waste stream, and in general the limited possibilities of utilising heat.

Gasification

Small scale gasification is one of the most efficient means of extracting energy from biomass. It also offers the prospect of using biomass instead of petroleum products to power internal combustion engines. In principle, gasification therefore represents an attractive option for countries that lack fossil fuel resources, or have an abundance of biomass resources, or simply wish to shift towards renewable energy.

Gasification should be particularly attractive in tropical countries with high biomass productivity, where residues from crops and other forms of biomass can be used for electricity generation.

Evidence from the projects developed to date suggests that there are two main markets for small-scale gasification:

- Captive power plants for small-scale industries that otherwise depend on diesel generators, either due to lack of grid connection or unreliability of grid supply
- Electrification of villages and semi-urban areas as Independent Rural Power Producers

The first market has tended to be more successful, as it generally involves private sector financing based on a sound business plan. In contrast, rural electrification projects are frequently developed by non-profit institutions such as government agencies, parastatals, cooperatives or NGOs. They may secure project funding and then hand over to the final owner, which is often a community-based organisation or a cooperative.

When a technical or financial problem arises, the local organisation often lacks the necessary resources and expertise to resolve the problem and has weak technical back-up, highlighting the importance of the business model used. Particularly in Africa, gasification has a slightly troubled history, with many projects not able to sustain operation beyond the initial period. The main issue in most of these cases is a combination of a technology too sophisticated for the context, plus an inappropriate business model. However, success stories do exist. Gasification has been successfully implemented by some companies, for example Husk Power. It operates hybrid mini grids powered by rice husk gasifiers combined with solar PV. At the moment, Husk Power has 75 sites operating in India and five in Tanzania.

Table 2: Active support programmes for bioenergy

Programme	Main activities
Africa Biogas Partnership Programme	The Africa Biogas Partnership Programme (ABPP) is a Public-Private Partnership engagement programme which aims to provide access-to-energy services through the installation of biogas digesters in partnership with local enterprises, NGOs, and governments. The programme ended in March 2020 and was active in Ethiopia, Kenya, Tanzania, Uganda and Burkina Faso.

Industry associations

The **World Bioenergy Association (WBA)** is an international NGO and non-profit association that represents the bioenergy sector globally. The organisation works to promote the use of sustainable bioenergy. The secretariat of the WBA is in Stockholm.

The **World Biogas Association** is the global trade association for the biogas, landfill gas and anaerobic digestion sectors, dedicated to facilitating the adoption of biogas globally. It represents all organisations working in the biogas industry at the international level across the world, including national associations, biogas operators and developers, equipment providers, water companies, the agricultural sector, waste companies, and academic and research institutions.

References and further reading

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Biogas from Energy Crop Digestion
https://www.ieabioenergy.com/publications/biogas-from-energy-crop-digestion/

Useful contacts

UNIDO regional centres for Renewable Energy and Energy Efficiency
East African Centre for Renewable Energy and Energy Efficiency (EACREEE) -
http://www.eacreee.org/

ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE)
http://www.ecreee.org/

Himalayan Centre for Renewable Energy and Energy Efficiency (HCREEE)
http://www.hcreee.org/

SADC Centre for Renewable Energy and Energy Efficiency (SACREEE)
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