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Technical Guide: Bioenergy

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Bioenergy refers to all energy derived from biological sources, including 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 bioenergy in Africa is unsustainable and inefficient for the most part. In sub-Saharan Africa, only 17% of the population had access to clean cooking fuels and technologies in 2020 with this lower in rural areas. The remaining 83% of the population primarily rely on traditional biomass sources such as wood and charcoal, alongside other dirty fuels such as kerosene. Bioenergy use for cooking increases health problems and mortality rates as a result of the indoor air pollution that it can cause when burnt inefficiently. However, there is huge potential for deploying modern, efficient biomass fuels and technologies at the household level, as well as for institutions and industry.

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, management of biomass based waste and reduced dependence on imported sources of energy. However, to generate bioenergy at scale, careful consideration is needed to ensure that it is done in a responsible and sustainable manner to avoid potential negative impacts such as competition with land for food production, eviction of small holder farmers and deforestation.

Bioenergy can be classified in two main categories: 'traditional' and 'modern'. Traditional bioenergy typically refers to the combustion of biomass such as 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 biomass-based 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 an important primary energy source across the African continent. It is primarily used for cooking and heating at the household level, 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. As such, charcoal production can lead to forest degradation and become a driver for deforestation.

Typically, wood is used for cooking in rural areas and collected rather than harvested, whilst charcoal is primarily an urban fuel which is bought, often in small quantities, for daily use. Given high levels of urbanisation and low social and economic barriers for its use, charcoal consumption is expected to rise in sub-Saharan Africa.

The use of wood fuels in households is associated with indoor air pollution and the respiratory diseases that result when particulate matter and carbon monoxide (CO) are released during combustion. A separate commercialisation guide on clean cooking looks into improved biomass 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 industries, the increased efficiency of combustion technology and more sustainable methods of harvesting wood fuels are both areas 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 the 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 several wood-based power plants operating in Ghana, Congo, Ethiopia, Tanzania, Namibia and Eswatini, and a number of new plants planned or under construction.

Biomass residues

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

- Wood logging residue, specifically 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 or a mixture of manure and bedding materials.
- Agro-processing residues generated at 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 by IRENA 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. There are also efficiencies in using the final energy form close to the source of production; for example, an agri-processing facility using waste materials to generate electricity or biogas that can be used on site to power operations. Circumstances in which the owner of the residues is the one running the bioenergy conversion facility would be most favourable, as no contracts and agreements need to be drawn up with the owners of the residue. In some cases, the asking price for these waste residues can go up once the supplier realises the bioenergy producer will need them to run the conversion processes and is making a valuable product from them. Strategies to avoid this can include long-term pricing agreements or co-investment with the resource owner so they have an incentive in providing the materials at the lowest cost. In some cases, the waste and residues may have negative environmental impacts, such as the need for storage space, emission of decomposition gasses (typically methane), or generating some other environmental pollution. 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 within 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 recent past due to poor project planning, insufficient marketing, low quality products and lack of availability of appropriate stoves.

Briquettes generally come in two main types. Carbonised briquettes are made from biomass that has been carbonised (through a pyrolysis process) and as such burn similarly to charcoal and can be suitable to replace charcoal at the household level. Uncarbonised briquettes, made from biomass that has not been carbonised (such as sawdust or bagasse), are more suitable to replacing firewood in industrial or institutional applications. Non-carbonised pellets can also be used in gasifier stoves at the household level.

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.

Supporting government policy and favourable tax tariffs will be important in developing the bioenergy potential of African countries. For example, the Kenya Ethanol Cooking Fuel (ECF) Industry Masterplan, launched in 2021, assessed what is required to scale up local production in the country and policy recommendations for growing the local industry.

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 to 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 biofuels 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. As with all feedstocks, understanding their local availability, ownership of the resource and competing uses is important in assessing their potential and sustainability.

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, briquettes or liquid biofuel which may be used for heat for cooking or industrial processes, 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 amendment 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: disposal of organic waste material such as animal waste, human waste, or other organic materials (from agricultural waste, slaughterhouses, etc) so they 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. Uptake has been supported by National Biogas Programmes in several countries such as those supported under the Africa Biogas Partnership Programme. 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 currently available. Traditional brick dome digesters 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. Another type of digester is the 'Plastic Bag Digester', a prefabricated plastic biodigester designed for farmers in developing countries, also commonly known as a tubular plastic digester. The device, which is UV-resistant, can be manufactured locally and installed in one day. Other models, such as those promoted by Sistema.bio, may be imported.

Despite the significant reported benefits of small-scale biodigesters, biodigesters have relatively low penetration in sub-Saharan Africa. Cultural aversions to using manure for cooking, issues with feeding the biodigesters with animal manures which are not collected easily, and logistical challenges with transporting manure as feedstock, are all amongst the challenges summarised in Table 1. 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. Considerations for promotion of the technology include:

- The functionality of biodigesters is a key challenge. Well-trained and motivated technical staff for the reliable construction of fixed dome digesters, farmer training, aftersales services and quality assurance can support a sustainable, market-oriented sector. Regularly feeding the biodigester is key to ensure its long-term functionality.
- 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.
- The high costs of installation and maintenance can deter interest in biodigesters and a clear value proposition must be presented to farmers for the technology to be attractive.
- 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. The agronomic and economic value of the bioslurry must be promoted among farmers.
- 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.

Agriculture and rural extension programmes can also be channels to provide training and awareness on biogas technologies. They can also facilitate access to finance and provision of capacity building to microfinance institutions and farmers. Innovative financing mechanisms need to be supported, such as the use of existing agriculture structures (e.g. cooperatives and Savings and Credit Cooperative Organisations known as SACCOs) for the provision of microfinance or lease-to-own facilities.

Figure 2. Anaerobic digester by HomeBiogas. Source: BBOXX.

Recently, a number of innovative projects have piloted biogas on a Pay-As-You-Go (PAYG) principle. The main characteristic of solar PV PAYG, the ability to remotely shut down the system in case of non-payment, is something technology providers have been struggling with for biodigester technology. BBOXX started a pilot in East Africa, working with HomeBiogas, in which customers will get a biodigester, cookstove and smart valve that allows them to pay-as-they-cook. ATEC Biodigesters International have also developed a PAYG biodigester system for last-mile farmers in Cambodia. Remote monitoring software, such as Smart Biogas by Inclusive Energy, is also making it easier for companies to collect data about the use of their biodigesters which can support maintenance and customer service activities.

Whilst the use of biogas at source is the most common approach, upgrading biogas and storing it in pressurised containers for distribution is an approach that has been implemented in parts of India. However, this approach has had little uptake in sub-Saharan Africa due to a lack of technical expertise, appropriate technology, scale of production and distribution infrastructure. Innovations in AD technology, cleaning and upgrading of biogas to allow compression, bottling and development of distribution systems may all be required to support this approach, along with new business models and supportive policy.

Table 1. Summary of barriers for household and farm level biodigesters

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 set up 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 (for plastic bag digesters). • Insufficient feedstock and/or time and money.
Socio-cultural	• Preference of cooking the traditional way with firewood stoves. • Inertia around 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 and 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, including 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 onsite use, feeding into the national grid or wheeling to third-party users, as well as generating 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, 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, relating 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 such as the difficulty of securing feedstock, the general absence of proper waste management, lack of financial incentives to invest in improved waste management when dumping agricultural waste typically costs farmers little or nothing, unclear environmental legislative frameworks that might classify digestate as a hazardous waste stream, and in general the limited possibilities around 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 their 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 operates hybrid mini-grids powered by rice husk gasifiers combined with solar PV. At the moment, Husk Power has over 130 sites operating in India, Tanzania and Nigeria.

Table 2. Active support programmes for bioenergy

Programme	Main activities
African Biodigester Component (ABC)	ABC is a 5-year programme, running until December 2025. The programme aims to create sustainable biodigester markets in 5 countries; Burkina Faso, Kenya, Mali, Niger and Uganda. **https://english.rvo.nl/subsidies-programmes/african-biodigester-component-abc#**
Africa Biogas Partnership Programme	The Africa Biogas Partnership Programme (ABPP) was a public-private partnership engagement programme which aimed 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. **https://www.africabiogas.org/**
Bioenergy for Sustainable Local Energy Services and Energy Access in Africa	Implemented by NIRAS-LTS with Aston University, E4tech and AIGUASOL the two-year research project ran from June 2019 - Sept 2021 and was part of the Transforming Energy Access (TEA) programme, funded by aid from the UK Government. The research focused on opportunities for anaerobic digestion (AD) and combustion for electricity and/or heat generation in the range 10 kW to 5 MW and focused on seven prioritised demand sectors. **https://www.niras.com/projects/bioenergy-for-sustainable-local-energy-services-and-energy-access-in-africa-bseaa-2/**

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.

The **Clean Cooking Alliance (CCA)** works with a global network of partners to build an inclusive industry that makes clean cooking accessible to the three billion people who live each day without it, including support to bioenergy solutions for cooking.

References and further reading

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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) http://www.sacreee.org/

Modern Energy Cooking Services Programme
https://mecs.org.uk/
mecs@lboro.ac.uk

World Bioenergy Association (WBA)
Kammakargatan 22
SE 111 40 Stockholm
Sweden
https://worldbioenergy.org/
info@worldbioenergy.org

World Biogas Association
Sustainable Bankside II
25 Lavington Street
London
United Kingdom
+44 20 3735 8116
https://www.worldbiogasassociation.org/
info@worldbiogasassociation.org

Clean Cooking Alliance
+1 202.887 9040
https://www.cleancookingalliance.org/
info@cleancookingalliance.org