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SUSTAINABLE DEVELOPMENT GOALS



GREEN COOKING: SUSTAINABLE PATHWAY TO ACHIEVE SDG 7

COUNCIL ON ETHANOL CLEAN COOKING

WORLD BIOENERGY ASSOCIATION

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Executive Summary

The current stage of market introduction of green cooking technologies in Sub-Saharan Africa lies between pilot phase and isolated cases of successful regional deployment. Only a limited number of examples have reached significant scale. As a result, recognition of these three technologies as meaningful and sustainable solutions for cooking fuel supply is often lacking, despite existing evidence showing that each of them can deliver clean cooking at significant scale and lower cost than LPG. At the same time, they offer a sustainable cooking solution based on local resources that is independent of volatile global fossil fuel markets, does not require foreign exchange and creates a local energy economy.

The recently published IEA report on universal access to clean cooking in Africa (IEA, 2025) presents a scenario of accelerated deployment of clean cooking solutions across the continent. In this ACCESS scenario, green cooking technologies play a significant role. By 2040, 80 million people could be cooking with biogas, according to the scenario, still far below the tremendous potential of 110 billion cubic meters of biogas equivalent. Ethanol use for cooking could grow from the current 750 million litres to 6,4 billion litres, and modern solid biomass use could provide 215 PJ—equivalent to approximately 16 million tons of pellets.

The potential is clearly there. There are substantial economic benefits, both at the user level and for local and national economies. The question, then, is: why is dissemination so slow? This report explores that question and highlights the opportunities and challenges associated with green cooking. The short answer is that there has been little serious capital invested in these sectors, and only few economic operators have recognized the huge potential of green cooking.

Ethanol and pellets are tradeable fuels and share several common challenges. Both can be produced at small scale, enabling decentralized approaches to fuel production and use. However, they still require substantial capital investment and technical expertise to operate successfully. This creates the well-known “chicken and egg” challenge of investing in fuel production without an existing market. In the case of ethanol, imports have been used to overcome this barrier—an approach that has not yet been tested for pellets, although pellets are traded globally at considerable scale.

Most pellet producers have instead relied on relatively small-scale production. However, many of these plants lack the technical capacity to operate consistently at full capacity, frequently encounter operational problems, and struggle to ensure supply security, consistent product quality, and economic break-even. In many cases, this is linked to underinvestment and limited operator experience with pelleting technologies.

Another key challenge for ethanol and pellets is standardisation and certification of quality. In a future market that supports fuel trading and the wide dissemination of cookstoves across different countries, standards should, as far as possible, be harmonized. In the case of pellets, existing standards cannot simply be copied, as the raw materials available in Sub-Saharan Africa (SSA) differ significantly from those used in Europe or North America—the largest pellet markets to date. In addition, gasifying cookstoves have different—fortunately less stringent—quality requirements than, for example, European pellet heating equipment.

A critical issue for biogas, as well as for pellets and ethanol, is the availability of after-sales services. This is more difficult than it seems, given the large geographical size of countries, weak transport infrastructure, and the limited availability of skilled technical personnel. Nevertheless, such services are essential, and the absence of repair and maintenance has led to the failure of entire dissemination programmes.

This underscores the importance of training and skills development as an integral part of market development. Training needs to cover the entire value chain, from staff in financial institutions that fund investments, to public administration personnel who provide supportive regulatory environments, to entrepreneurs who build and operate production plants, and finally to technicians (or owners) who can repair cookstoves or biogas installations.

Equally important to managing supply side challenges is the development of the demand side. The most significant barrier on the demand side is the high upfront cost of cookstoves or biogas equipment. Cooking with firewood on a three-stone fire involves no monetary cost, while a basic charcoal stove may cost only $3-5, whereas ethanol or pellet cookstoves can cost up to 10 times more. There are various approaches to address this challenge, including pay-as-you-go models, carbon-credit-based mechanisms, and microfinance solutions. These approaches need to be widely available and well designed to enable a large-scale transition to green cooking.

Commercial and institutional uses of green cooking fuels can help to rapidly scale demand and make investments in fuel production commercially viable. This requires dedicated efforts, the selection of suitable technologies, and targeted marketing, but such uses can become an important stepping stone towards the development of a functioning and reliable supply chain.

A key factor for mainstreaming green cooking is sustained and professional communication through mass and social media to raise awareness of its benefits and help generate demand. Individual economic operators, often working with limited budgets, can fund sales teams but cannot afford large-scale media campaigns or well-designed, ongoing public relations activities. This creates a need for cooperative structures and dedicated funding mechanisms.

Another common challenge across green cooking technologies is the need for stronger advocacy. The limited recognition of these technologies is closely linked to a lack of coordinated advocacy. Green cooking solutions require coherent and well-aligned policies across various ministries. This highlights the role of associations and similar organizations in promoting sector interests and supporting the development of coordinated policy initiatives.

In Europe, the ethanol, pellet, and biogas industries have established national and regional organizations that promote sector interests. These organizations also provide statistics on demand and supply trends, prices, and technologies, which are essential for establishing transparent markets and building public and investor confidence. Capacity-building efforts should include the establishment and support of such organizations as long as the respective sectors remain too small to sustain these organisations independently.

Green cooking technologies offer such significant benefits and have such large quantitative potential that they clearly warrant increased attention from policymakers, financial institutions and the broader economy.



Sistema.bio | Biogas for Thermal Uses

Foreword

Universal access to clean, reliable, and affordable cooking energy is essential to the achievement of SDG 7 and sustainable development. While global efforts to expand clean cooking have accelerated, progress remains uneven, and many households continue to rely on fuels and technologies that undermine health, environmental sustainability, and economic resilience. Addressing this challenge requires solutions that move beyond cleanliness alone to support long-term structural transformation. In this context, UNIDO advances green cooking as a strategic pathway for developing countries including LDCs and SIDS.

UNIDO's mandate integrates energy access with industrial development, job creation, and climate action. In many developing countries, prevailing cooking fuels—traditional biomass, charcoal, kerosene, and imported fossil fuels—contribute to deforestation, household air pollution, and growing fiscal and foreign exchange pressures. Although liquefied petroleum gas and electricity can play important roles, their expansion is often constrained by infrastructure requirements, import dependency, and the need for sustained public subsidies.

Green cooking provides a complementary and sustainable alternative. Based on renewable bioenergy sources, such as biogas, ethanol, and sustainably produced modern solid biomass pellets, green cooking solutions deliver clean and efficient cooking while strengthening local value chains. These fuels can be produced from locally available agricultural residues, organic waste, and sustainably managed biomass, enabling decentralized production, enterprise development, employment creation and women empowerment.

From the perspective of UNIDO, WBA, CECC and other like-minded partners, green cooking is distinctive in its integration of energy access with productive and industrial activities. Biogas systems link cooking energy with waste management and bio-fertilizer production. Ethanol connects agriculture with modern fuel markets and agro-processing. Improved solid biomass fuels enhance efficiency, reduce pressure on forests, and support local manufacturing and distribution. Together, these approaches improve energy security, create employment, and contribute to climate mitigation and adaptation, as well as savings from foreign exchange loss.

This publication reflects our commitment to promoting scalable, market-based green cooking solutions. It assesses the current state of technologies, identifies constraints to scale, and highlights the policy, investment, and institutional measures required to unlock sustainable cooking energy markets. By positioning green cooking within broader development and industrialization agendas, the report underscores its potential to contribute meaningfully to the Sustainable Development Goals.

UNIDO and its partners consider the transition to green cooking a strategic investment in inclusive industrial development and environmental sustainability. This publication aims to support governments, development partners, and the private sector in advancing coordinated action to bring green cooking solutions to scale.

Gustave Aboua
Interim Chairperson of CECC



1

GREEN COOKING WITH BIOGAS

SAJIDAS APPUKUTTAN
(BIOTECH INDIA)

VERENA BRUEGELMANN
(SISTEMA.BIO)

XUNAXI CRUZ
(SISTEMA.BIO)



1.1 Introduction to Biogas Technology

Energy and waste management are two of the most critical challenges faced by societies worldwide. With increasing population, urbanization, and industrialization, the demand for clean and renewable energy sources is continuously growing. At the same time, improper waste management has led to environmental pollution, health hazards, and climate change. **Biogas technology**, also known as *biomethanation*, offers an effective solution that addresses both these challenges. It is a proven, reliable, and sustainable method to convert organic waste into useful products such as biogas and organic fertilizer.

Biogas is a clean, combustible gas mixture consisting primarily of methane (CH_4) and carbon dioxide (CO_2), produced by the **anaerobic digestion** of biodegradable materials. The technology has gained global recognition due to its multiple benefits, including energy generation, organic waste management, environmental protection, and contribution to the Sustainable Development Goals (SDGs). Please refer to Figure 1 for an illustration of the potential of biogas to contribute to the SDGs.

Biogas technology has a long history. In its early stages, it was introduced as a scheme primarily for farmers who owned cattle. Cattle dung, available in abundance, was the initial raw material used for gas production. Rural households adopted small-scale biogas plants to produce cooking gas while also generating organic fertilizer that could be applied to farmlands.

Over the decades, **continuous research, innovation, and development** transformed this technology from a simple rural scheme into a versatile solution applicable across different sectors of society. Researchers discovered that not only cattle dung, but almost all types of organic waste could be utilized as feedstock. This widened the scope of biogas technology and made it attractive for urban households, restaurants, institutions, and industries.

One of the significant milestones was the development of **portable and prefabricated biogas plants**, which reduced installation time, lowered costs, and made the technology more user-friendly. These innovations expanded the accessibility of biogas plants to both rural and urban areas. Today, biogas technology is considered one of the most practical approaches to achieving renewable energy generation, waste reduction, and environmental sustainability.

Biogas technology is highly versatile in terms of raw materials. While cattle dung remains a traditional and popular choice, modern plants can utilize a wide variety of

biodegradable waste materials, including other livestock manures (e.g. swine and poultry), such as:

- **Agricultural residues:** straw, husks, stalks, and crop residues.
- **Food and kitchen waste:** vegetable peels, leftovers, canteen waste, and household organic waste.
- **Market waste:** spoiled fruits, vegetables, and organic residues from markets.
- **Slaughterhouse waste:** blood, fats, and animal waste.
- **Agro-industrial by-products:** press mud, bagasse, distillery effluent, dairy waste, and waste from oil production, etc.
- **Sewage and municipal waste:** organic fraction of municipal solid waste and sewage sludge.

The ability to digest diverse feedstocks makes biogas technology one of the most flexible and adaptable renewable energy systems. It not only generates energy but also **manages organic waste hygienically**, reducing health risks and environmental pollution.

Biogas plants in rural areas provide clean cooking fuel, reducing smoke and health risks while replacing firewood and kerosene. They produce nutrient-rich organic fertilizer, boosting soil fertility and crop yields. By reducing firewood use, they curb deforestation and ease women's workload. By offering decentralized, renewable energy, biogas enhances rural energy security, supports livelihoods, and fosters sustainable development.

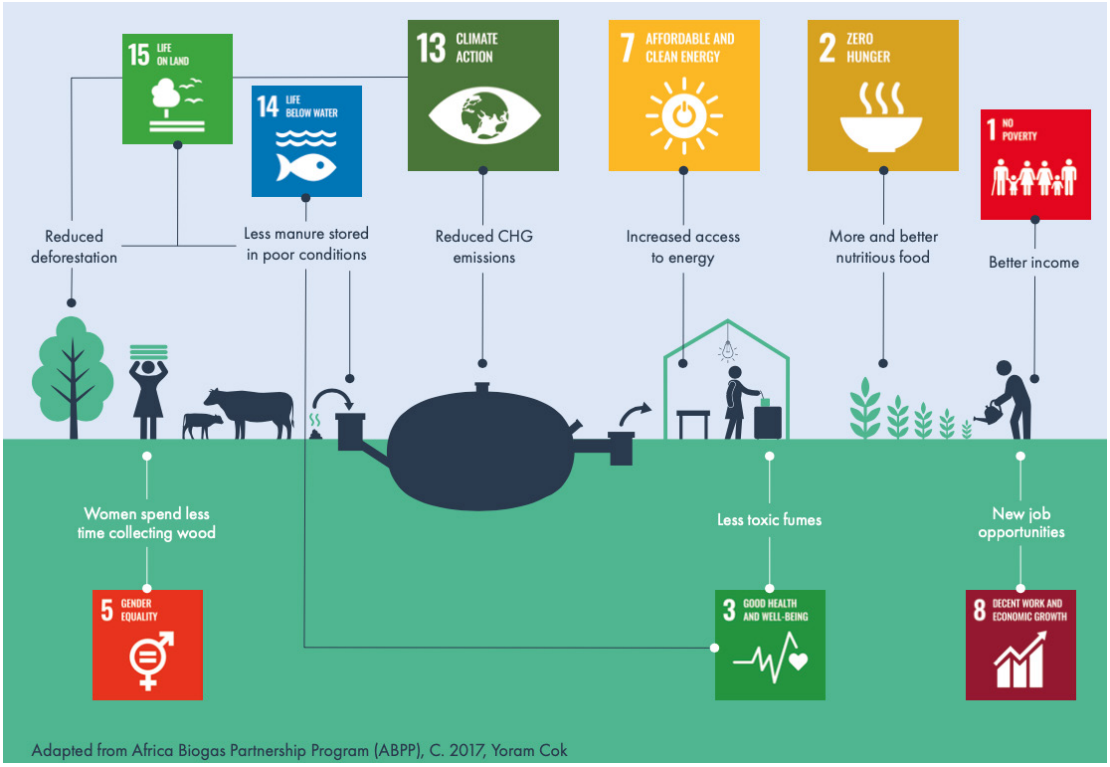


Figure 1: Shell Foundation report on demonstrating the potential of biogas to contribute to the SDGs.

Biogas technology in urban areas addresses waste management and generates renewable energy. Households and communities use portable or larger plants to process kitchen waste, reducing LPG use by more than 50 per cent. Hotels, restaurants, and institutions convert food waste into cooking gas or electricity. Municipal plants process the organic fraction of municipal solid waste (MSW), reducing landfill loads, improving sanitation, and advancing zero-waste and sustainable city goals.

Biogas technology has grown from a rural energy option for cattle-owning farmers to a globally relevant sustainable solution. Its versatility in feedstock use enables the provision of clean cooking fuel, organic fertilizer, and waste management services, while reducing dependence on LPG, firewood and charcoal. By reducing pollution, supporting the circular economy, conserving forests, and lowering carbon emissions, it contributes to climate action. In addition, carbon credit opportunities enhance its value, positioning biogas as a key driver in the global green energy transition. Practical and inclusive, biogas remains vital for renewable energy, environmental protection, and a cleaner, greener, and more sustainable future.

According to a study commissioned by Gold Standard, biogas projects generate the highest socio-economic value among carbon programme categories. Biodigesters reduce emissions while also improving health, saving time, reducing energy costs, producing organic fertilizer, and creating rural jobs.[1]

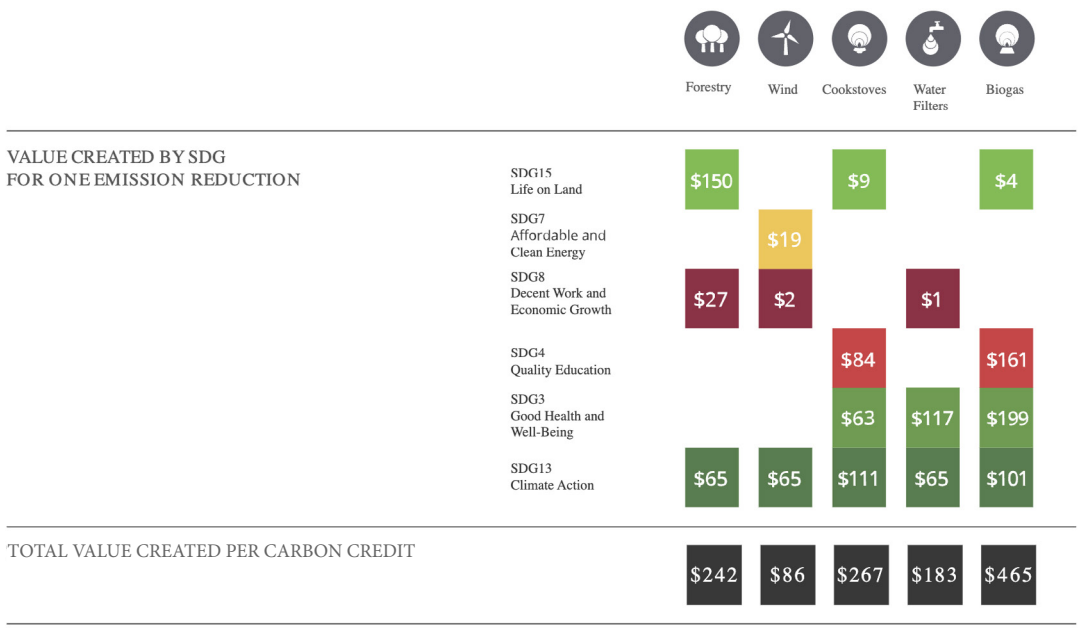


Figure 2: Average co-benefits across different project types, per tonne of CO_2e (Gold Standard).

[1] https://www.goldstandard.org/we-are-all-about-impact/how-shared-value-is-calculated-for-gs-certified-projects.

1.2 Technologies to Produce Biogas at Different Scales

What makes biogas technology unique is its **adaptability**. It can be implemented at different scales—from small, family-sized digesters serving a single household to large commercial plants capable of generating compressed biogas (CBG) for vehicle fuel and pipeline injection. Over the years, innovations in plant design, feedstock utilization, and gas purification techniques have expanded the scope of biogas technology across rural, urban, industrial, and municipal settings.

1.2.1 FUNDAMENTALS OF BIOGAS TECHNOLOGY

Biogas is produced by the **anaerobic digestion** of organic materials such as cattle dung, kitchen waste, agricultural residues, market waste, and industrial by-products. The process occurs in four stages—hydrolysis, acidogenesis, acetogenesis, and methanogenesis—resulting in the production of methane-rich gas.

The basic components of any biogas plant include:

- **Inlet chamber:** For feeding organic substrate into the digester.
- **Digester tank:** Airtight chamber where anaerobic fermentation takes place.
- **Gas holder/dome:** Collects the generated biogas.
- **Outlet/slurry tank:** Allows digested slurry to flow out for use as fertilizer.
- **Pipelines and appliances:** Transport and utilize the gas for cooking, heating, or power generation.

Depending on the **scale, purpose, and feedstock availability**, different designs and models of biogas plants are employed.

1.2.2 FAMILY-SCALE BIOGAS PLANTS

Family-size biogas plants (1–6 m^3/day) are designed to meet household cooking needs in rural, semi-urban, and urban areas. Common models include: **floating drum** (easy operation but prone to corrosion), **fixed-dome** (durable, low maintenance but costlier), **prefabricated portable plants** (FRP/HDPE, compact, ideal for urban kitchens), and **balloon/bag digesters** (low-cost, short lifespan). These plants provide clean cooking

fuel, manage household and cattle waste, and produce nutrient-rich slurry as fertilizer. Benefits include affordable renewable energy, reduced indoor air pollution, time savings for women, and up to 50 per cent reduction in LPG consumption in urban households.

1.2.3 INSTITUTIONAL-SCALE BIOGAS PLANTS

Institutional-scale biogas plants (25–250 m^3/day) are designed for schools, colleges, hospitals, hostels, canteens, religious institutions and community kitchens that generate large amounts of organic waste or cattle dung. Technologies include **large-capacity floating drum models**, **improved fixed-dome designs** with lower costs, **modular prefabricated systems** that can be scaled up, and **multi-stage digesters** for higher efficiency. Applications range from cooking in community kitchens and water heating to steam generation and electricity production. Examples include temple kitchens such as Tirupati and educational or healthcare institutions using food waste for energy. Benefits include reduced waste disposal challenges, lower LPG and diesel expenses, promotion of renewable energy awareness, and decentralized, sustainable energy solutions tailored to institutional needs.

1.2.4 COMMERCIAL AND INDUSTRIAL-SCALE BIOGAS PLANTS

Commercial and industrial-scale biogas plants, with capacities above 500 m^3/day and reaching several thousand cubic metres, are designed for municipalities, industries and large commercial establishments. These plants utilize advanced technologies, such as **continuous stirred tank reactors (CSTR)** for agro-industrial residues, **plug-flow digesters** for high-solids manure, **UASB reactors** for wastewater treatment, and **ASBR systems** for variable organic loads. **Dry fermentation** is applied to MSW, while **gas upgrading technologies,** such as water scrubbing, Pressure Swing Adsorption (PSA), membrane separation, and chemical absorption, convert raw biogas into Bio-CNG/CBG for vehicles or pipelines. Applications include electricity generation, industrial heating, compressed biogas as automotive fuel, pipeline injection, and large-scale waste treatment. Examples include Germany's farm-integrated plants, India's SATAT programme producing transport-grade CBG, and decentralized waste-to-biogas projects in Kerala. Benefits include renewable energy generation, waste reduction, job creation, carbon credit opportunities, and the development of sustainable green business models.

1.3 Technology Providers and Investment Cost of Biogas Plants

The global shift towards renewable energy and sustainable waste management has made **biogas technology** one of the most widely adopted decentralized energy solutions. Across the world, numerous technology providers—ranging from small-scale innovators to large engineering firms—offer biogas plants suitable for households, institutions, industries, and municipalities.

The cost of setting up a biogas plant varies significantly depending on its size, design, feedstock availability, and intended application. From portable family-size digesters costing a few hundred dollars to large commercial-scale plants involving millions of dollars, investment considerations are central to the adoption and scaling of this technology.

1.3.1 GLOBAL TECHNOLOGY PROVIDERS IN THE BIOGAS SECTOR

Biogas technology has matured over the past several decades, and today there are hundreds of technology providers worldwide. These companies differ in their focus: some specialize in **family-size biogas digesters**, while others cater to **industrial- and commercial-scale projects**.

1.3.1.1 Domestic Biogas Technology Providers

Domestic or family-size biogas plants are designed for households or small communities. They are widely promoted in countries with agricultural economies and high cattle populations.

BIOTECH INDIA (India):

A leader in family and institutional biogas projects, BIOTECH INDIA has installed thousands of small-scale plants using cattle dung and kitchen waste. Its innovation in **portable fibreglass digesters** has made the technology more affordable and accessible to both rural and urban households.

SNV Netherlands Development Organisation (Africa and Asia):

SNV has implemented large-scale domestic biogas programmes in countries such as Nepal, Viet Nam, Rwanda, and Ethiopia. Its work involves training masons, standardizing designs, and building capacity for rural households.

Fixed-dome models (China and South Asia):

China and Viet Nam are pioneers in fixed-dome digesters, which are widely adopted in rural areas. Millions of units are in operation, supported by government subsidies and extension programmes.

Sistema.bio (Mexico, Africa, Asia):

Sistema.bio is a leading biogas company operating across Latin America, Africa, and Asia that manufactures modular, prefabricated biogas plants for small farmers and institutions. Its approach combines high-quality prefabricated technology with training, after-sales service, and data-driven monitoring, targeted at improving rural livelihoods at scale while ensuring affordability.

1.3.1.2 Institutional-Scale Biogas Providers

Medium-scale biogas plants are used in schools, hospitals, temples, hostels, and community kitchens where large quantities of food waste or cattle dung are available.

BIOTECH INDIA (India):

Recognized for its expertise in designing and installing institutional biogas systems, BIOTECH INDIA has pioneered projects in temples, educational institutions, and public kitchens across Kerala and other states in India.

European providers (Germany and Denmark):

Medium-scale digesters in Europe focus on food waste and agro-industrial residues, often linked with combined heat and power (CHP) applications.

Sistema.bio (Mexico, Africa, Asia):

Sistema.bio has experience in both household and institutional-scale systems. The company designs and installs modular biodigesters for schools, commercial farms, and other types of institutions.

1.3.1.3 Commercial and Industrial Biogas Providers

Large-scale plants for industries and municipalities require advanced technology and significant investment. Providers specialize in digesters, gas upgrading systems, and integration with industrial processes.

Envitec Biogas (Germany):

One of the leading companies in commercial-scale projects, offering turnkey solutions from digester design to gas upgrading and grid injection.

PlanET Biogas (Germany):

Focuses on modular biogas technology for agricultural and municipal waste.

Xergi (Denmark):

Specializes in large anaerobic digestion projects, including dry fermentation for MSW.

1.4 Investment Cost of Biogas Plants

1.4.1 FACTORS INFLUENCING INVESTMENT COST

The cost of a biogas plant depends on multiple factors, including its **size, model, feedstock, location, and end-use of biogas**.

Size of the biogas plant:

- Small domestic plants (1–6 m^3/day) are low-cost.
- Institutional plants (25–250 m^3/day) require higher investment.
- Commercial/industrial plants (500+ m^3/day) involve major capital outlay.

Model and construction material:

- Fixed-dome plants (masonry) are cheaper but require skilled labour.
- Floating drum plants need steel, increasing cost.
- Prefabricated FRP/HDPE plants are more expensive per unit but portable and durable.

Type and quantity of feedstock:

- Uniform cattle dung is easy to handle.
- Kitchen waste requires shredders and pre-treatment, adding to cost.
- Industrial effluents may require advanced reactors (UASB, CSTR).

Biogas utilization:

- Cooking gas requires only pipelines and burners.
- Electricity generation requires biogas engines/generators.
- Bio-CNG production requires purification and compression units, significantly increasing investment.

Location and logistics:

- Transport of feedstock, labour costs, and infrastructure affect overall investment.

1.4.2 COST RANGE BY SCALE

Domestic biogas plants (family size):

- Capacity: 1–6 m^3/day.
- Cost: $400–1,200 (for portable fibreglass digesters).

- Example: A fibreglass digester priced at **$400** can generate 1 m³ of biogas daily—sufficient for cooking two meals for a small family.

Institutional biogas plants:

- Capacity: 25–250 m³/day.
- Cost: $5,000–50,000, depending on design, feedstock handling, and utilization system.
- Example: A 100 m³/day plant for a hostel kitchen may cost approximately $20,000 and provide gas for cooking and water heating.

Commercial and industrial biogas plants:

- Capacity: 500–5,000 m³/day or more.
- Cost: $200,000 to several million.
- Example: A large MSW-based biogas plant producing Bio-CNG may cost $5–10 million, depending on gas upgrading technology.

1.4.3 OPERATION AND MAINTENANCE COSTS

In addition to capital investment, ongoing expenses include:

- Labour for feeding and maintenance.
- Repairs and replacement of parts.
- Energy costs for pumps, agitators, or shredders.
- Periodic service contracts with technology providers.

Well-designed plants with proper operation and maintenance can achieve **payback periods** ranging from **two to seven years**, depending on scale and utilization.



1.5 Examples of a Business Case and Successful Biogas Programmes in Sub-Saharan Africa

1.5.1 THE SISTEMA.BIO BUSINESS CASE

1.5.1.1 Introduction

Sistema.bio is the world's leading biogas company for family farmers, with more than 150,000 biodigesters installed globally since its founding in 2010 in Mexico. The technology, financing models, and service approach have enabled farming families across Latin America, Africa, and Asia to access clean energy and regenerative agricultural solutions.

In Africa, Kenya has become the largest hub. Since 2017, more than 16,000 farmers have been equipped with biodigesters, complemented by financing, training, and long-term after-sales service.

With a headquarters in Nairobi and nine field offices across the country, the team has the capacity to install more than 300 digesters per month.

Beyond Kenya, Sistema.bio operates in more than 10 Sub-Saharan African countries, including Ethiopia, Ghana, Malawi, Senegal, Uganda, Tanzania, Zimbabwe, and Zambia, where the company is represented by local distributors and partners. This regional footprint allows Sistema.bio to adapt its model to diverse contexts, build strong local ecosystems, and scale solutions that improve livelihoods while reducing greenhouse gas emissions.

To ensure affordability and consistent quality, the company manufactures biogas digester kits in India under high-quality standards and ships them to markets in Africa and other regions. Centralized production allows Sistema.bio to achieve the economies of scale needed to keep prices low while guaranteeing durable, reliable systems for farmers worldwide.

1.5.1.2 Product and Service Offering

Sistema.bio's prefabricated biogas digesters are durable and easy to install, allowing farmers to process livestock manure and organic waste into clean energy and organic fertilizer. Installation is simple, and a small digester can be set up in as little as one day using prefabricated parts and basic tools. Once installed, the system is filled with water and manure to begin the start-up phase. The digester becomes fully active and ready for continuous use within a maximum of 30 days.

During operation, manure and organic waste are mixed with water on a daily basis and fed into the digester. Inside the oxygen-free chamber, naturally occurring microbes break down the material and release methane-rich biogas. The gas is collected in the flexible upper part of the reactor and delivered through long-lasting piping to stoves, burners, or other appliances, providing clean cooking fuel, thermal and mechanical energy for farm and household needs.

At the same time, the digestion process produces a steady flow of nutrient-rich effluent, known as ***bioslurry***. This organic fertilizer contains nitrogen, phosphorus, potassium, and organic matter in plant-available form, improving soil fertility, water retention, and crop productivity. Farmers can apply the slurry directly to fields or store it for later use.

Designed for tough outdoor conditions, Sistema.bio reactors are built to last at least 20 years on farms worldwide. Each unit is backed by a 10-year warranty, ensuring long-term reliability and farmer confidence. The key components of the system are shown in Figure 3 below.



Sistema.bio | The biodigester solution

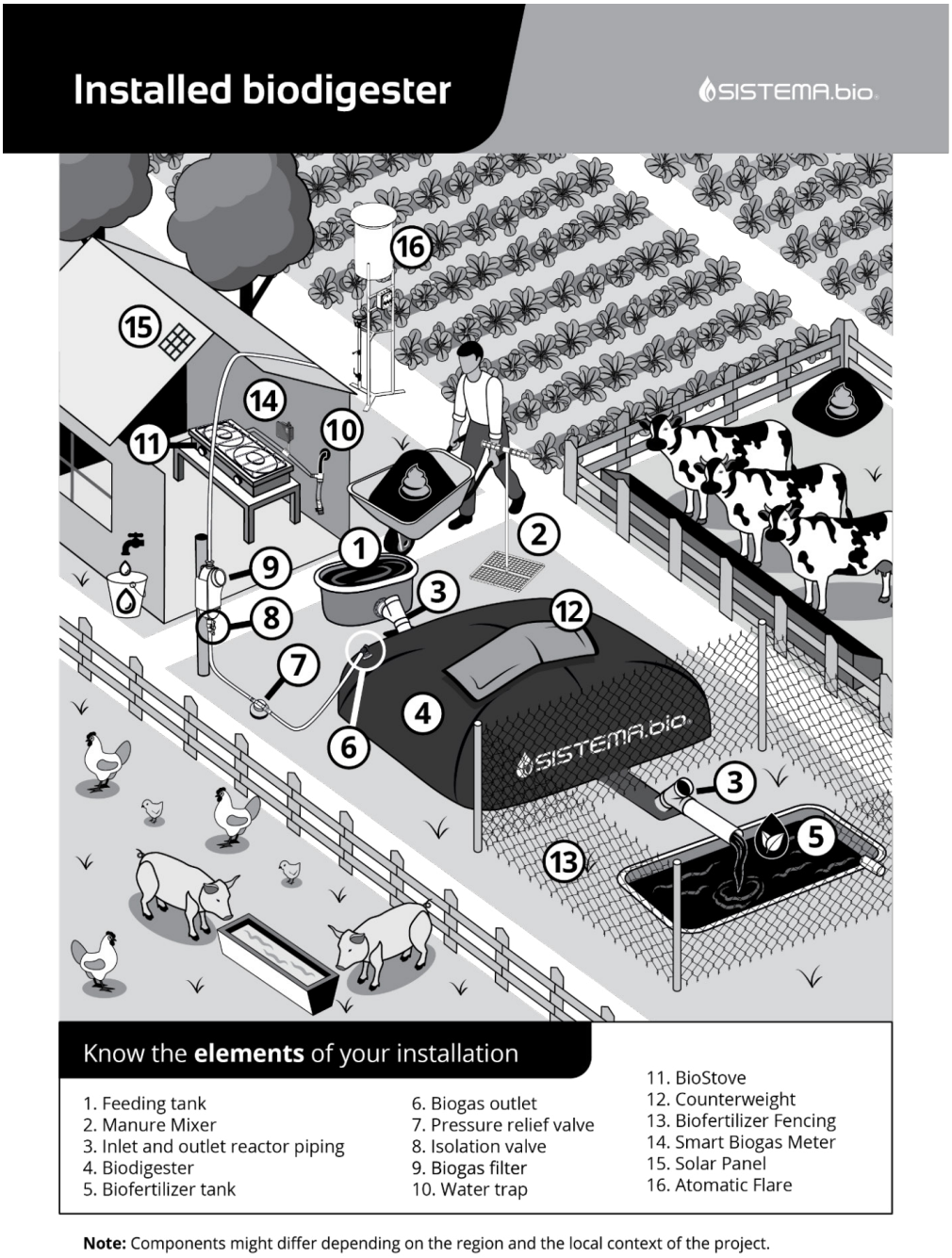


Figure 3: Sistema.bio patented complete biogas kit.

Sistema.bio's biogas technology can process as little as 35 kg of animal waste per day and up to 5 tonnes, meeting the energy and fertilizer needs of a wide range of farm types and sizes. The smallest unit is 6 cubic metres, while the largest standard unit is 40 cubic metres, and the system is modular in design, meaning that multiple reactors can be connected to expand capacity as needed. In addition to livestock manure, the digesters can also process other organic waste streams such as food waste, green waste, and sanitation-related organic waste.

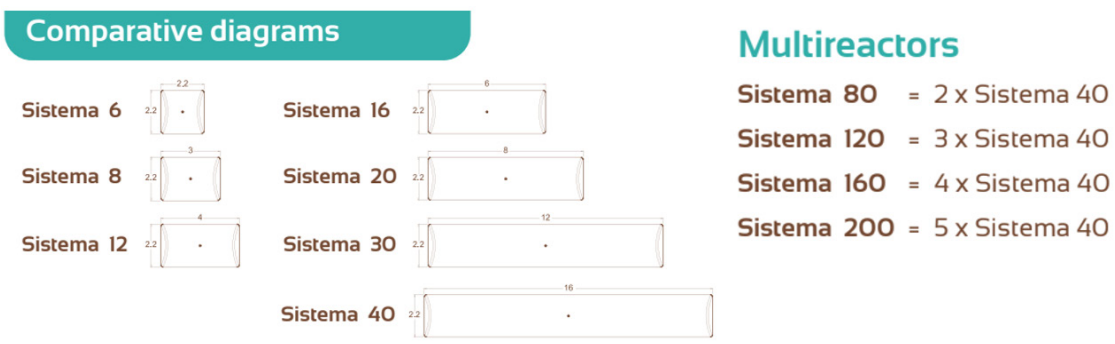


Figure 4: Available standard sizes of Sistema biodigesters.

Alongside its technology, Sistema.bio applies a proven methodology that covers farmer selection, installation, training, and ongoing service. Dedicated teams of installers, technicians, and support staff ensure quality at every stage, while farmers receive the training and after-sales support required for long-term success. These efforts are strengthened through partnerships across the supply chain and monitored through a digital data platform.

1.5.1.3 Scalable Business Model

Sistema.bio operates as a vertically integrated company, combining technology design and manufacturing, financing, service delivery, climate finance, and regenerative agriculture services. This integrated model ensures affordability for farmers while building long-term sustainability and scale.

Sistema.bio designs and manufactures high-quality, modular biodigester kits at scale in India. Centralized production achieves economies of scale, keeping costs low while ensuring durable and reliable systems. Kits are shipped to Africa, where local teams sell, distribute, and install them on farms.

Reliability and long-term customer satisfaction are central to Sistema.bio's approach. Regional field offices and trained technicians provide installation, farmer training, and technical support. Each biodigester is backed by a 10-year warranty, supported by ongoing maintenance and after-sales service, ensuring sustained use and impact.

Access to finance remains the primary barrier to adoption by smallholders. Sistema.bio works with microfinance institutions, SACCOs, farm cooperatives, and commercial banks to provide loans and flexible repayment terms suited to seasonal farm incomes. In Kenya, the company also operates an in-house credit department, offering flexible instalment plans directly to farmers and enabling adoption even where traditional credit is limited.

Carbon finance is fully embedded in the company's business model and is a key driver of affordability and scale. By registering methane abatement from biodigester adoption in global carbon markets, Sistema.bio secures climate finance revenues directly linked to farmer impact. These carbon revenues are deducted from the customer price, lowering upfront costs by an average of 60 per cent and making biodigesters more accessible to family farms.

Sistema.bio's portfolio includes a mix of voluntary and compliance carbon programmes, including projects certified by Gold Standard, Article 6.2 bilateral co-operation agreements, and emerging ITMO frameworks under the Paris Agreement. The company is also expanding into longer-durability removal credits through biochar and regenerative agriculture solutions. All projects are designed to align with the Core Carbon Principles (CCP), ensuring that credits meet high standards of integrity and deliver tangible climate and community benefits. This diversity of carbon offerings de-risks revenue streams, secures forward finance, and passes benefits directly to farmers.

Beyond energy production, biodigesters generate nutrient-rich bioslurry that can be used directly or processed into value-added regenerative agriculture products. Building on this, Sistema.bio has developed a product line that includes biofertilizers and soil and plant health solutions tailored to specific crops and local markets. These products increase farmer productivity, reduce dependence on chemical inputs, and create additional revenue streams, positioning biogas as a central component of the regenerative agriculture economy.

The model is inherently scalable. Global production ensures affordability through economies of scale, while regional hubs in Africa anchor distribution, training, and service networks. Financing partnerships and carbon revenue integration expand access, while regenerative product lines create new pathways for growth.

1.5.2 OTHER SUCCESSFUL BUSINESS MODELS IN SUB-SAHARAN AFRICA BIOGAS PROGRAMMES

1.5.2.1 Household Pay-As-You-Go (PAYG) Biogas Models

- **Concept:** Instead of high upfront payments, households access prefabricated digesters through instalment plans or mobile-money enabled PAYG systems.
- **Value:** Increases affordability and reduces the risk of non-payment.
- **Example:** Prefabricated biogas companies in Kenya and Tanzania bundle installation, maintenance, and financing. Customers repay gradually using savings from reduced LPG or charcoal purchases.

1.5.2.2 Institutional Biogas Models (Schools, Hospitals, Prisons)

- **Concept:** Large cooking facilities install digesters to utilize food and animal waste, directly substituting firewood or LPG.
- **Revenue/Benefit:** Main savings come from reduced fuel costs and improved waste management. Fertilizer use in institutional farms can add value.

- **Example:** Ugandan schools have installed biogas units that supply cooking gas for canteens while using slurry for agricultural training gardens.

1.5.2.3 Community-Based Cooperative Models

- **Concept:** Farmer cooperatives pool livestock manure into communal digesters. Biogas is shared for cooking, while fertilizer is redistributed for crop production.
- **Value:** Shared investment reduces individual costs and strengthens community ownership.
- **Example:** Rural cooperatives in Ethiopia and Tanzania have piloted cooperative plants with mixed success; strong governance is critical.

1.5.3 LESSONS FROM SUCCESSFUL BUSINESS MODELS

1. **Multiple revenue streams are essential.** Projects relying only on cooking gas sales struggle; adding fertilizer markets, waste fees, or carbon income strengthens financial viability.
2. **Partnerships matter.** Municipal, private sector, and community stakeholders each play critical roles (policy, capital, feedstock, customer base).
3. **Affordability mechanisms drive uptake.** PAYG, instalment finance, and results-based subsidies help households and institutions overcome initial investment barriers.
4. **Service quality builds trust.** After-sales support, warranties, and technician training reduce system failures and ensure long-term adoption.
5. **Policy and finance alignment unlock growth.** Clean-cooking initiatives, municipal waste policies, and climate funds need to work in tandem.

Biogas in SSA is no longer confined to donor-funded household units; it is evolving into a diverse sector with viable business models that link energy, agriculture, and waste management. The Kisumu market case highlights how urban waste challenges can become profitable clean energy ventures when multiple stakeholders collaborate. PAYG household systems, institutional digesters, agro-industrial plants, and municipal waste-to-energy projects all demonstrate pathways to sustainability.

Scaling these models requires continued investment in blended finance, strong policy support, and the professionalization of supply chains. With these enablers in place, biogas can deliver affordable clean cooking, reduce urban waste, generate jobs, and contribute meaningfully to climate goals in SSA.

1.6 Overview of Current Biogas Market Development in Sub-Saharan Africa

1.6.1 MARKET POTENTIAL FOR BIOGAS IN SUB-SAHARAN AFRICA

Africa holds one of the world's largest untapped markets for household and productive-use biogas. According to SNV's *Technical Potential for Household Biodigesters in Africa* study, an estimated 32.9 million households across the continent meet the basic technical requirements for biodigester use, determined mainly by sufficient livestock holdings and access to water.

The highest technical potential is concentrated in livestock-rich countries such as Ethiopia (5.4 million households), Nigeria (3.5 million), Uganda (3.1 million), Tanzania (2.4 million), Kenya (2.3 million), and Sudan (2.2 million). Together, these countries account for more than half of Africa's overall potential, with millions of farmers able to benefit from biodigester technology.[2]

This potential is driven by **two urgent needs**:

i. a **sustainable replacement for wood fuel and charcoal**, which still supply over 80 per cent of household cooking energy and contribute to deforestation, soil degradation, and health risks; and

ii. a **source of affordable, nutrient-rich organic fertilizer** to restore soils, improve productivity, and reduce dependence on costly imported chemical fertilizers.

Biogas directly addresses both challenges, making it one of the most relevant clean energy and regenerative agriculture solutions for the region.

Biogas in SSA is transitioning from donor-led pilot projects and household digesters towards more diversified markets that include institutional systems, municipal organic waste plants, and early commercial activity for compressed/ upgraded biogas (CBG/

[2] Technical potential for household biodigesters in Africa: https://a.storyblok.com/f/191310/61a849e3e2/technical_brief_-_technical_potential_for_household_biodigesters_in_africa.pdf?utm_source=chatgpt.com.

Bio-CNG). Progress is uneven: pockets of mature activity exist (notably Kenya, Uganda, Rwanda and parts of East Africa), while large parts of the region remain underserved. Recent years have seen renewed public–private funding, blended finance pilots, and technical programmes (capacity building, prefabricated small digesters) designed to scale both household and market-oriented solutions.

1.6.2 MARKET LANDSCAPE AND RECENT DEVELOPMENTS

i. *From household to market-based models.* Longstanding household programmes (e.g., those supported by SNV's Africa Biogas Partnership Programme and related initiatives) have created thousands of household digesters and built local supply chains. Over the last 3–4 years, activities have shifted towards commercialization, including demand aggregation, private suppliers of prefabricated units, and pay-for-service models that lower upfront cost barriers. These programmes now explicitly target market viability, including sales, after-sales service, and carbon revenue streams.

ii. *Urban organic waste-to-energy pilots.* Cities are piloting organic waste collection and centralized anaerobic digestion for municipal and market waste (including food markets). Examples include donor-backed projects that convert market and municipal organic waste into biogas for local energy use or transport fuel. The Kisumu (Kenya) market biogas project is a clear example of linking informal settlement and market waste collection to anaerobic digestion. Such pilots are important because they demonstrate economics of scale, circular economy benefits, and municipal collaboration.

iii. *Blended finance and clean cooking facilities.* New financing vehicles (e.g., Modern Cooking Facility for Africa, MCFA) and regional climate and clean-cooking funds have begun to make risk capital and concessional finance available to providers in Kenya, Tanzania and beyond. This support helps bridge the critical "valley of death" between pilots and commercial rollout.

iv. *Evidence and research informing policy.* International agencies (such as the International Energy Agency [IEA]) and national energy reviews are increasingly incorporating biogas into clean cooking and renewable energy outlooks, signalling stronger policy recognition and future planning integration at national levels. National reviews (e.g., Kenya's 2024 energy policy review) report thousands of digesters in operation and identify biogas as part of the national renewable energy mix.

1.6.3 COUNTRY SNAPSHOTS (SELECTED)

- **Kenya:** Active market with tens of thousands of digesters reported in national surveys, supported by strong private suppliers and donor partnerships. Kenya is experiencing growth in both household systems and municipal and market-waste pilots.
- **Uganda:** Long experience with institutional systems and NGO-driven household programmes; recent projects focus on valorisation of slurry (organic fertilizer markets) and carbon revenue streams to improve project economics.
- **Rwanda:** Early national household biogas efforts, with continued institutional interest. Reported operational inefficiencies and user-experience challenges highlight the need for stronger quality control and after-sales service. Rwanda also issued recent competitive tenders for small-scale systems.
- **Ethiopia:** A large national biogas programme implemented by SNV and the Ethiopian Government led to the installation of thousands of digesters, mainly fixed-dome systems, making it one of the largest programmes in Africa. High system default rates have been reported. Academic and pilot activities are increasing, with research on feedstock variability and biogas performance; however, adoption remains constrained by limited access to finance and competing clean-cooking policy priorities.
- **Tanzania, Ghana, Nigeria, and others:** Scattered pilots and emerging commercial entrants are present. Some countries are beginning to pilot CBG and municipal anaerobic digestion for organic waste, but large-scale commercial roll-out remains limited.

1.7 Key Issues to Stimulate Market Growth for Clean Cooking with Biogas

Sub-Saharan Africa has strong preconditions for biogas: abundant organic feedstock from livestock, markets and agro-processing; high demand for clean cooking; and growing interest from Governments and development partners. However, the sector remains fragmented, with limited commercial activity and many short-lived pilot initiatives. To establish a dynamic and self-sustaining market, policy alignment, predictable financing, reliable technology, and strong service networks must advance together. Sustainable biogas growth in SSA requires a portfolio approach: scaling reliable prefabricated household and institutional systems while selectively developing municipal and biomethane projects. Progress will depend on coordinated action across policy, finance, standards, skills, data, and market development, ensuring the sector moves from fragmented pilots to a stable, commercially viable market.

1.7.1 CLEAR POLICY FRAMEWORKS AND CROSS-SECTORAL ALIGNMENT

Biogas spans energy, waste, agriculture, and climate policy, but these domains often operate separately. When coordination is weak or mandates are unclear, projects struggle to secure permits and long-term revenue streams, and private investment becomes riskier.

Recommended actions:

- Recognize anaerobic digestion and biomethane as eligible technologies in national clean-cooking and energy strategies.
- Include biogas and biomethane pathways in municipal waste plans, with procurement mechanisms that enable public-private partnerships (PPPs) for organic-waste treatment.
- Align incentives across energy, fertilizer and carbon markets.

- Integrate biogas into nationally determined contributions (NDCs), mitigation and adaptation plans, methane-reduction strategies, and manure-management policies so that climate benefits can be formally accounted for and monetized.

1.7.2 SUSTAINABLE FINANCING, FISCAL POLICY AND BLENDED INSTRUMENTS

High upfront costs remain the primary barrier for households, institutions and commercial anaerobic digestion plants. Taxes on equipment, limited access to long-term credit, and uncertainty around carbon revenues increase financing risk and make early projects difficult to structure.

Recommended actions:

- Apply VAT exemptions or reduced import duties for certified digesters, stoves, and productive-use equipment to improve affordability.
- Use blended finance (grant, concessional, and commercial capital) to de-risk early investments and attract lenders.
- Provide results-based subsidies linked to verified installation, performance, and measured methane reductions.
- Expand pay-as-you-go and asset-finance models for households, schools, and small institutions.
- Establish predictable access to carbon markets, including clear national procedures for authorization, monitoring, and revenue flows, so carbon income can reliably lower user contributions and support long-term operation.

1.7.3 MARKET-GRADE SUPPLY CHAINS AND AFTER-SALES SERVICE

Many early biogas programmes failed due to weak installation quality, unreliable components, and inadequate maintenance, resulting in system abandonment and user disillusionment.

Recommended actions:

- Certify installers and standardize system components.
- Promote service models that ensure warranties, spare parts availability, and regular maintenance.
- Support local SMEs and franchise-style approaches for last-mile installation and repairs.
- Develop registries or digital platforms to track installed units and system performance.

1.7.4 AGGREGATION MODELS FOR FEEDSTOCK AND DEMAND

Institutional and municipal plants require stable feedstock supply, while household systems become more affordable when communities procure in bulk. Without aggregation, many projects cannot reach viable scale.

Recommended actions:

- Organize structured collection of market, hotel, and restaurant waste, with space for informal sector participation.
- Support cooperatives, MFIs, and municipalities to aggregate demand for household systems.
- Pilot hub-and-spoke models with central digesters processing waste from surrounding communities.

1.7.5 TECHNOLOGY FIT AND QUALITY STANDARDS

Feedstocks and cooking practices vary widely across the region. Technologies not adapted to local conditions often underperform, undermining user confidence and slowing market uptake.

Recommended actions:

- Promote modular, prefabricated digesters for consistent installation and reliable performance.
- Invest in simple pre-treatment solutions for mixed waste and upgrading technologies where biomethane is targeted.
- Establish national and regional standards for biogas digesters, installers, and appliances.
- Fund applied R&D through universities, innovation hubs, and private-sector partnerships.

1.7.6 DATA, MONITORING AND QUALITY ASSURANCE

Investors and policymakers require credible performance and emissions data to justify funding and scale-up. Weak monitoring slows investment and obscures best practices.

Recommended actions:

- Standardize monitoring protocols for gas production, uptime, and slurry quality.
- Use digital tools such as IoT devices and mobile apps to improve system oversight.
- Publish aggregated performance data to strengthen investor and government confidence.

1.7.7 INSTITUTIONAL CAPACITY BUILDING AND LOCAL ENTREPRENEURSHIP

Growing markets depend on trained technicians, capable local SMEs, and informed regulators. Many countries lack structured training pathways and extension systems that incorporate biogas.

Recommended actions:

- Support vocational training for technicians, masons, and service providers.
- Provide business development support for SMEs to expand from small pilots to larger portfolios.
- Integrate biogas into agricultural and energy extension services.
- Strengthen partnerships between universities, research centres, and industry to improve designs and operational practices.

1.7.8 COMMUNICATION, BEHAVIOUR CHANGE AND USER-CENTRED DESIGN

Adoption depends on trust, local cooking patterns, and awareness of financial and health benefits. Systems that are poorly explained or poorly aligned with user habits often fall out of use.

Recommended actions:

- Conduct public awareness campaigns on cost, health and fertilizer benefits.
- Support demonstration sites in schools, farms, and communities.
- Leverage early adopters and farmer networks for peer-to-peer learning.
- Ensure gender-responsive engagement, with solutions tailored to household cooking needs.



2

ETHANOL FOR GREEN COOKING

WUBSHET TSEHAYU
AND HARRY STOKES
(PROJECT GAIA)



Project Gaia

2.1 Introduction

Modern ethanol cooking technology provides a safe, clean and renewable alternative to traditional fuels. Ethanol, a simple alcohol (C_2H_5OH), is produced through the fermentation and distillation of sugar- or starch-rich feedstocks such as molasses, sugarcane, cassava, sweet or grain sorghum, a wide variety of fruits and tuberous plants, as well as market wastes and agricultural residues. During alcohol production, yeast ferments sugars and starches into ethanol, which is then distilled to the desired purity for use as a fuel. Naturally occurring enzymes are used to convert starch to sugar in starchy feedstocks. To safeguard users and discourage misuse, ethanol fuel is denatured with additives that make it unsuitable for drinking. Ethanol is easily coloured to mark its purpose for fuel. Denatured ethanol fuel has been in use at scale for well over a century.

Highly effective, efficient and safe ethanol stoves were first developed in Sweden in the 1970s, widely popularized in Europe and the United States over the following 30 years, and were introduced in Africa in 2000 (Schoonraad, Swanepoel, & van NieKerk, 2001).

Ethanol stoves are now in regular use in Ethiopia, Madagascar, Nigeria, Kenya, Uganda, Tanzania, and Mozambique. They were introduced in refugee programmes in Ethiopia in 2005 as part of an effort by the United Nations High Commissioner for Refugees (UNHCR) to provide cooking fuel where forest biomass was constrained. Pilot programmes and commercial activities alike have demonstrated ethanol's strong safety record, high levels of user satisfaction, and its ability to reliably replace biomass and fossil fuels in both household and institutional settings, including refugee camps and cooking centres (Tsehayu & Getaneh, 2016). Field-based indoor air studies, as well as laboratory testing, have shown that ethanol cooking can dramatically reduce PM2.5 (fine particulate matter) emissions and emissions of CO (carbon monoxide) and NOx (nitrous oxides) (Benka-Coker, Tsehayu, Milano, Getaneh, & Stokes, 2018).

Ethanol is used in specially designed stoves that ensure safe and efficient combustion and safe handling of liquid fuel. Among the various designs, non-pressurized, spill-proof ethanol stoves with refillable adsorptive canisters have emerged as the most widely adopted technology. In these systems, liquid ethanol is adsorbed onto a dense mineral fibre packed into a canister with a closable mouth that allows the fuel to vaporize into a combustion chimney, where it is burned with air mixing. The correct mixture of ethanol vapour and air is essential for efficient combustion, producing a clean, hot flame with minimal emissions other than CO_2 and water vapour. Studies consistently show that ethanol stoves can lower household exposure to harmful pollutants and reduce the risk of respiratory diseases caused by smoke from traditional fuels (Alexander, ***et al.***, 2017) (Easton, 2017).

Modern ethanol stoves deliver strong performance. They achieve thermal efficiencies above 60 per cent, translating into faster cooking times, lower fuel consumption, and reduced household cooking energy costs. They ignite quickly without pre-heating, and their flame size is easily adjustable, giving users control over cooking temperatures. Because the stoves are non-pressurized and virtually spill-proof, and ethanol flames can be extinguished with water, they provide significantly enhanced safety compared to LPG and kerosene stoves (Project Gaia, Inc., 2025) (Blue Flame Stoves, 2025a) (Koko Networks, 2024).

Stove design and construction have progressed over the past 20 years of use in Africa to enhance durability, adaptability and economy of manufacture. Ethanol stoves in use in Africa are manufactured in Nairobi (Kenya), India and China. Some stoves are produced in local machine shops with manual tools, but have not yet achieved the quality and performance of industrially manufactured models. The use of high-quality materials such as stainless steel, galvanized steel, and aluminium is recommended to withstand prolonged exposure to heat and the corrosive effects of combustion. Ethanol stoves are available in both single- and double-burner models. Their compact, portable and user-friendly design makes them practical in diverse environments, from urban homes and rural villages to refugee camps.

Ethanol production relies on well-established fermentation and distillation methods. Ethanol fuel can be produced cost-effectively at almost any scale, from a few hundred litres per day to many thousands of litres per day. It can therefore be produced for local distribution through small, decentralized supply chains, or for regional, national, or international distribution through centralized, highly integrated supply chains. The adaptability of ethanol to local production and use creates opportunities for energy independence, rural development, and local energy self-reliance. At the same time, ethanol is positioned as a scalable solution for clean cooking (UNIDO, 2024).

Ethanol cooking technology brings together a proven fuel with robust, practical stove designs. It has more than two decades of successful real-world use in Africa. Its flexibility and track record make it a practical, safe, and sustainable choice for advancing clean cooking goals worldwide.



Figure 5: IEA cooking stoves assessment of performance against key metrics (International Energy Agency, 2023. "A vision for Clean Cooking Access of All").

2.2 Overview of Ethanol Grades and Uses

Ethanol is classified into different quality grades based on purity, production processes, and end-use, with each grade serving distinct applications. Extra Neutral Alcohol (ENA) is the purest grade and is used for food and beverages. Rectified Extra Neutral (REN) and lower-grade REN are commonly used for industrial purposes and clean cooking. Motor-fuel-grade ethanol is designed for blending with gasoline for motor fuel use. Technical Alcohol (TA) is a lower-quality ethanol containing a higher share of distillery by-products, especially higher-carbon alcohols. Methylated spirit typically consists of lower-quality ethanol mixed with methanol. It is used as a denatured industrial product. It is also used as a liquid or gel fuel for cooking and chafing dishes (Project Gaia, 2015).

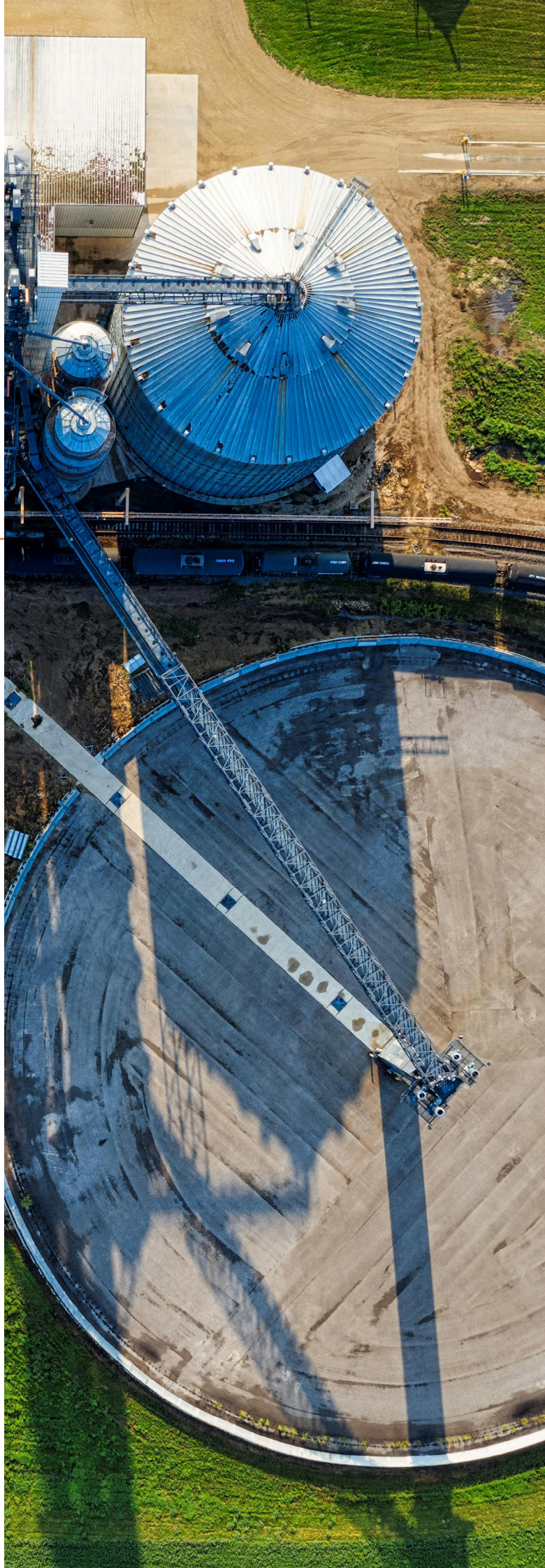


Table 1: Types of ethanol, description and typical uses.

Type of Ethanol	Description	Typical Use
Extra Neutral Alcohol (ENA)	Highest-quality ethanol, highly purified, produced mainly for the food and beverage industry	Beverages, pharmaceuticals, food applications
Rectified Extra Neutral (REN) Ethanol / Rectified Spirit	Industrial-grade ethanol with very low impurities; minimum 95-96 per cent alcohol by volume	Clean cooking fuel; also used medicinally, as a solvent or cleaner, and in industrial products
Low-grade REN (REN-B)	Lower-grade rectified ethanol (minimum 95 per cent alcohol by volume) with slightly higher impurity levels; also called "Korean Grade B"	Industrial feedstock for further rectification; can be used as stove fuel
Fuel-grade Ethanol	Produced for blending with petrol (E5, E10, E85); has different distillation configuration	Transport sector; blending in petrol in line with ASTM D4806 or EN 15376 standards
Technical Alcohol (TA)	By-product from rectification, typically around 85 per cent ethanol with water and light/ heavy distillation fractions	Industrial uses; occasionally stove fuel, but with lower combustion cleanliness; often used to produce gel fuel for cooking
Methylated Spirit (Industrial Denatured Spirit)	Denatured ethanol, usually 70 or 95 per cent strength, with additives such as methanol and blue or purple dye	Medical, cleaning, and industrial solvents; sometimes used as stove fuel

2.3 Technologies to Produce Ethanol Cooking Fuel at Different Scales

Ethanol production technology for cooking fuel relies on well-established fermentation and distillation processes that can be adapted to different scales. Feedstocks rich in sugars or starches, such as molasses, sugarcane, cassava, corn, and sweet or grain sorghum, are first prepared through cleaning and size reduction via milling, crushing, or grating, depending on the feedstock type. For sugar-rich feedstocks such as sugarcane or sweet sorghum, juice is extracted through crushing, while molasses can be diluted and used directly as a fermentation substrate. For starchy feedstocks such as cassava, corn, or grain sorghum, the material is milled or grated and cooked with water to produce a slurry. Enzymes are then added to convert starch into fermentable sugars. Yeast ferments these sugars into ethanol under controlled temperature and pH conditions, producing a mash containing ethanol, water, and residual solids. Maintaining clean operating conditions and stable fermentation parameters is essential to achieve high ethanol yields and consistent product quality.

After fermentation, the ethanol-rich mash undergoes distillation, where heat separates ethanol from water and solids. Micro-distilleries often use batch pot stills or simple column stills because of their affordability and simplicity, while small and large plants tend to employ continuous multi-stage distillation columns with heat-recovery systems to improve efficiency. Depending on the intended use, ethanol can be distilled to a maximum strength of 95.6 per cent alcohol by volume (ABV).

Micro-distilleries producing up to approximately 5,000 litres per day can be located close to farms and rural communities because of their small size, minimizing feedstock transport costs and providing a decentralized supply of clean cooking fuel. Larger distilleries integrated with sugar mills, grain refineries, or other industrial facilities can serve large, urban and national markets and benefit from economies of scale. Across all scales, appropriate safety measures, waste management, and quality control are essential, making ethanol production a mature and adaptable technology for delivering renewable cooking energy.

2.4 Overview of Ethanol Production Scales

Ethanol for clean cooking can be produced at a range of scales, each with distinct technologies, feedstock requirements, operational advantages, and market applications. Understanding these production levels is critical for selecting an approach suited to local resources, infrastructure, and demand conditions.

2.4.1 MICROSCALE PRODUCTION (MICRO-DISTILLERIES: 500–5,000 LPD)

Micro-distilleries are decentralized facilities designed to serve local cooking fuel markets and rural communities. They typically process agricultural residues, molasses, sugarcane juice, cassava, or sweet sorghum using fermentation and relatively simple distillation systems. These plants can be configured as batch or continuous systems, with pot-type or column distillation units selected according to capacity and efficiency requirements. Micro-distilleries are compact, relatively low cost, and can be established close to smallholder farms to minimize feedstock transport and align ethanol production with local feedstock supply.

There is long-standing experience with micro-distilleries in Brazil, India, and other countries where smallholder farmers are the norm. Demonstration micro-distilleries were constructed in Ethiopia and Nigeria in 2012 and 2015 to provide cooking fuel and showcase advanced distillery designs capable of operating under constrained infrastructure conditions (Project Gaia, 2012) (Project Gaia, 2015). An ethanol stove business in Madagascar, Nosy Maitso, has since developed several micro-distilleries to supply fuel for its stoves (EEP Africa, 2025), with facilities fabricated locally (Sandstø, 2023) (Nosy Maitso, 2026).

Capital investment for micro-distilleries typically ranges from $200,000 to $1,000,000, depending on plant size, boiler systems, fermentation capacity, quality control equipment, waste treatment, and safety measures. Unit capital costs are generally below $1.00 per annual litre of capacity, making them reasonably cost-competitive with larger plants. Typical plant lifetimes are 15-25 years. Their competitive advantage often lies in access to low-cost feedstocks, lower labour costs, and a lower environmental footprint. These systems are well suited to rural communities and to pilot projects designed for capacity-building and intended scale-up (UNIDO, 2024).

2.4.2 SMALL-SCALE PRODUCTION (5,000–50,000 LPD)

Small-scale plants bridge local and national supply chains. They are generally located in intensively developed agricultural areas, where feedstock supplies are consistent. These plants generally employ automated fermentation vessels, multi-stage distillation columns, and energy-recovery systems to achieve higher conversion efficiency and consistent product quality.

Small-scale facilities can integrate with existing agro-processing industries, farmer cooperatives or outgrower schemes, creating stable markets for surplus crops or by-products. They support the development of extended distribution networks, with ethanol stored in bulk and delivered through regional depots to urban centres. Typical capital investment ranges from approximately $10 million to $50 million or more, depending on capacity and level of integration. Many African sugar plant distilleries fall into this category; they are large operations by African standards but remain small compared to plants in countries such as the U.S. and Brazil.

2.4.3 LARGE-SCALE PRODUCTION (50,000+ LPD)

Large-scale industrial ethanol plants, generally exceeding 50,000 LPD, are usually part of large sugar mills or grain-based refineries. These facilities are highly automated and include sophisticated process controls, dehydration systems for high-purity ethanol, and combined heat and power (CHP) units to improve overall energy efficiency.

Large-scale plants benefit from economies of scale, making them cost-effective for national programmes and large commercial fuel markets where demand is stable and predictable. They can supply both cooking fuel and transport fuel through shared infrastructure and may also produce valuable co-products such as animal feed and distillers grains. These facilities are most viable in countries with established sugar or grain sectors, existing fuel blending mandates, and supportive biofuel policies (Bacovsky, Matschegg, Janssen, Rutz, & Di Costanzo, 2022) (Baraneedharan, 2024).

Although capital-intensive, large-scale plants generally benefit from lower-cost financing. They can provide a long-term, reliable fuel supply, and enable integration with broader national energy and energy transition strategies.

2.4.4 EXAMPLES OF ETHANOL MICRO-DISTILLERY TECHNOLOGY PROVIDERS

Table 2: Selected manufacturers of ethanol production equipment.

Manufacturer	HQ / Primary Region	Website
Spectrum Global Projects Spectrum Technologies Ltd.	India	spectrum.bz spectrumbio.net
Logichem Process International	South Africa	logichem.com
Praj Industries	India / Global	praj.net
Dedini Indústrias de Base	Brazil	dedini.com.br
Shrijee Group	India	shrijee.com
Advance Biofuel	India	advancebiofuel.in
Attaquant Enterprises	India	attaquantepl.com
Santa Efigênia	Brazil	alambiquessantaefigenia.com.br
Limana Poliserviços	Brazil	limana.com.br/index.html
Taian Gaodeng Co., Ltd	China	machinerybest.com
King Mongkut's University of Technology Thonburi (KMUTT)	Thailand	sustainable.kmutt.ac.th/energy-and-climate-change/renewable-energy-usage/
CIST	Kenya	https://cistafrica.co.ke/

2.5 Business Models

2.5.1 KOKO NETWORKS: AN ETHANOL COOKING BUSINESS IN KENYA

Until recently, KOKO Networks in Kenya was the largest commercial ethanol cooking fuel programme in SSA. Launched in Nairobi in 2019, the company expanded to serve more than 1.3 million households across twelve major cities. Its model combined large-scale, decentralized fuel distribution with digital payment and a cloud-based monitoring system and incorporated carbon finance as a core revenue stream (MIGA, 2025). Recently, carbon finance revenues to KOKO Networks were interrupted when the company sought to shift from the voluntary carbon market to an Article 6 (regulated) market, which required approval from the Kenyan government. Due to concerns over carbon accounting across international boundaries, the need for highly reliable verification, and the potential impact on its NDC commitments, Kenya decided not to approve an Article 6 agreement. As a result, KOKO Networks abruptly ceased operations, interrupting the supply of fuel and cookstoves to its customers (Munang, 2026) (Olingo, 2026) (Rattenbury & Peters-Stanley, 2026).

The foundation of KOKO's business was a dedicated fuel distribution and handling system linked to neighbourhood retail access points. Ethanol was purchased in bulk by its fuel logistics partner, Vivo Energy, and stored in underground tanks at service stations operated by the company. From these depots, small tanker trucks delivered fuel to "KOKO Points," automated dispensers installed inside local retail shops. Households used refillable 2.3-litre bottles with integrated safety valves provided by the company to purchase small quantities of fuel—any amount up to the bottle's capacity—with 2.3 litres sufficient for several days cooking. This system allowed households to access fuel locally, a short distance from home, without the need for a costly large purchase or the direct handling of liquid ethanol (Koko Networks, 2025a).

KOKO's fuel bottle is equipped with a needle valve to ensure safe, controlled filling and dispensing. The bottle is filled at the KOKO Point by the consumer, carried home, and docked to the stove in an inverted position. The burners must be off for the bottle to dock with the stove. As ethanol is discharged from the bottle into the stove, it is adsorbed onto mineral fibre in a tank beneath each burner. This binds the ethanol, prevents leaks or spillage, and supports a steady fuel feed to each burner for controlled combustion. Back pressure from a full stove prevents overfilling from the bottle (Koko Networks, 2025b).

KOKO's elaborately engineered liquid fuel dispensing system, moving fuel from storage tanks to KOKO Points to stoves, uses cellular eSim data transfer, cloud-based data storage, and Near Field Communication (NFC) between devices. This adds tracking and inventory control to the supply chain. It also introduced substantial cost, complexity, and potential points of failure. One advantage of this highly developed, trackable system is the ability to generate data, which can be helpful not only in managing inventory and sales, but also in providing data to support and verify carbon finance claims. However, KOKO did not use its electronic data for this purpose, instead relying on household surveys to support its carbon credit claims. It is possible that the electronic data did not support a robust yield of credits and, therefore, Koko's management preferred the manual and less accurate method to support its claims.

In 2022, KOKO registered a clean cooking programme under the Gold Standard, an international standard for the voluntary carbon market, and was able to capture carbon credits retroactively from 2020, when it had begun sales in Kenya (The Gold Standard Foundation, 2026). Under this programme, KOKO generated verified emission reductions by switching households from charcoal and kerosene to ethanol. Revenues from carbon credit sales in the voluntary market were initially used to offset stove costs, and later fuel costs as well. KOKO used subsidies on both fuel and stoves to accelerate its growth.

Although KOKO has not provided a transparent accounting of its costs, its stove subsidy enabled a retail price to its consumers of 1,500 Kenyan shillings (KES), about $12, even though its internal cost for its stove was apparently above $100. More costly yet was its subsidy on fuel. Over time, KOKO's fuel procurement costs rose from about $0.70 to $1.50 per litre, while KOKO kept its retail price about KES 100 or $0.80 per litre. This price is competitive with or lower than the price of charcoal. KOKO's carbon finance programme thus directly supported household affordability and uptake. However, the scale of the subsidy on both stoves and fuel raised questions about sustainability of the business. Many observers questioned how long KOKO could keep its business going (Price, 2026) (Techcabal, 2026) (The Kenyan Wall Street, 2026).

Launched in Nairobi in 2019, KOKO had expanded by 2024 to other Kenyan cities, including Mombasa, Kisumu, Eldoret, and Nakuru, and had also launched a programme in Rwanda (RDB, 2022). Accelerating growth and carbon finance revenues may have been KOKO's strategy for outpacing its deficits.

As the business developed, KOKO became entirely dependent on revenue from carbon finance rather than on the sale of its core products, particularly its fuel. Each stove sold required a one-time subsidy, which, given the high cost of the KOKO stove, was substantial. More costly still, each unit of fuel sold also required a subsidy. This is a recurring daily subsidy that requires more finance as the number of stoves grows. This dynamic could lead only to one outcome: a ballooning subsidy requirement that would be difficult to finance, whether from the voluntary or the Article 6 market.

KOKO's original plan was for its fuel partner, Vivo Energy, to import ethanol in bulk at commodity prices, typically around $0.50 per litre, low enough not to require a subsidy. KOKO had requested Kenya and the EAC to distinguish ethanol fuel from potable alcohol and remove or reduce excise duty on this product, as is done in most ethanol fuel markets. However, EAC governments have

protected their distilleries for many decades and have been reluctant to lift their excise duty on any ethanol product, regarding the tariff as a spur for growth in domestic production. This increased the cost of KOKO's fuel by 35 percent. Moreover, the Kenyan government imposed on KOKO the condition that it was to exhaust its requirement for fuel through domestic procurement first, prior to being given a license to import ethanol. This left KOKO prey to a domestic industry that was not ready to meet KOKO's need for supply and price of fuel. This locked KOKO into its need to subsidize the fuel, whether or not this had been a part of its original plan.

The example of KOKO Networks shows that ethanol cooking can be deployed at scale. It shows how technology can open markets and how decentralized retail distribution can increase household access to ethanol fuel. It demonstrates one way of combining commercial investment with carbon revenues to address affordability. And it provides an example of private-sector partnerships solving challenges in logistics and infrastructure. But it also shows that the fundamental business proposition must be financially feasible and, if carbon finance is to be used, it must fit within a business model that works, not one solely reliant on externalities. KOKO's original approach was for carbon finance to subsidize stoves to promote a rapid increase in numbers and thereby generate high-volume fuel sales. The original approach to fuel sales was to exploit global commodity pricing of ethanol through efficient bulk imports, selling fuel at cost plus a modest return to the business. Instead, the subsidy on fuel coupled with the high overheads of the business rendered the business highly vulnerable, and it quickly failed when the carbon finance was interrupted.

The evidence suggests that the Kenyan government's policy priorities were not perfectly aligned with KOKO's, and that the government's support for KOKO was uneven. The government did remove VAT from fuel sales and from the sale of ethanol stoves, whether locally made or imported. It allowed KOKO's stove, manufactured in India, to enter Kenya duty-free. It adopted the Kenya Ethanol Cooking Fuel Masterplan in 2021 and the Kenya National Cooking Transition Strategy in 2024, in which it envisioned that 30 per cent of households would transition to ethanol cooking by 2028 (Ministry of Energy and Petroleum, 2024) (SSN, 2021) . However, it also sought to compel domestic production of ethanol fuel at the expense of fuel imports and placed the burden for spurring production on the market KOKO was creating. The government refused to remove excise duty on imported ethanol and the efforts it undertook to support the growth of domestic ethanol production were inadequate. The failure of the domestic market to meet the demand created by KOKO was the beginning of the end for KOKO's business. Thus, it was not only the loss of carbon finance that led to KOKO's closure, but also the lack of access to affordable fuel.

KOKO's closure has left a large number of ethanol stove users stranded. New businesses may arise to serve this market. Some are already minor players. For example, the Cleancook stove (see 2.6.1) is manufactured in Nairobi. Substantially cheaper than the KOKO cooker, it is affordable to many without subsidy. However, given the Kenyan government's determination to promote locally produced fuel, the true bottleneck is the supply of ethanol. More ethanol production must be developed, whether as part of the sugar industry or from other feedstocks. At the same time, existing ethanol producers must be

encouraged to show interest in the ethanol fuel market, diversifying away from Extra Neutral Alcohol (ENA) for beverages, a market rooted in the past (Baraneedharan, 2022) (Baraneedharan, 2024).

2.5.2 CONSUMER'S CHOICE LTD.: A LOCAL ETHANOL COOKING BUSINESS IN TANZANIA

The partnership between UNIDO and Consumer's Choice Limited (CCL) in Dar es Salaam demonstrates how ethanol can be introduced into an urban cooking fuel market by a small, locally owned and self-financed business. Launched as part of a multi-year clean cooking programme supported by the Global Environment Facility (GEF), the European Union, and the Government of Tanzania, the UNIDO programme set an ambitious target of transitioning more than 160,000 households from charcoal to ethanol by stimulating local businesses to take up the challenge. The UNIDO approach integrates international technical and financial support with reliance on private-sector investment and entrepreneurship, creating an opportunity for local business development and sustainability (UNIDO, 2023a) (Qu, *et al.*, 2025).

CCL is a Tanzanian logistics and supply chain company experienced in moving liquid cargo such as molasses and ethanol from producers to processors and end users. CCL's ethanol cooking business model is built on its core competency of managing supply chains. It is centred on local stove assembly and citywide distribution of stoves, supported by the creation of a local supply chain for ethanol cooking fuel. "Cleancook" ethanol stoves, manufactured in Nairobi and imported duty-free to Dar es Salaam under an established East African Community (EAC) trade agreement, are assembled locally to reduce costs, create employment, and build local capacity. Ethanol fuel, purchased from one or more sugar factories in Tanzania, is transported in CCL-owned tanker trucks to Dar es Salaam, stored in CCL's secure tank facilities in the city, and then denatured, bottled, and prepared by CCL for distribution to both small and large retailers, or delivered directly into neighbourhoods through CCL's retail agents. Fuel is bottled in a semi-automated plant on CCL's premises. Bottle distribution requires very low upfront investment compared to fuel vending machines and is a familiar means of fuel retailing. By leveraging Tanzania's established fast-moving consumer goods (FMCG) channels, CCL ensures that stoves and fuel are available through familiar outlets where households already purchase daily necessities. This approach makes ethanol accessible and convenient while also generating jobs in assembly, warehousing, trucking, distribution, and shop-based retail.

Although self-financed and not able to achieve the rapid growth that KOKO did during its start-up period, CCL has nevertheless delivered tangible results. By 2025, more than 20,000 stoves had been sold across several wards in Dar es Salaam, supported by consistent fuel distribution. Fuel sales have been market-based, with CCL earning a small profit. The initiative demonstrates that ethanol fuel can penetrate large urban markets on a commercial basis when supply and retail systems are designed to meet consumer needs for convenience and

accessibility, while remaining economically viable. Early adopters of the Cleancook stove report cleaner kitchens, faster cooking, and reduced smoke exposure, reinforcing the health and safety case for ethanol. CCL has incorporated these benefits into its marketing. UNIDO's support—providing technical backstopping, strengthening local business capacity, aiding promotion and marketing, and improving affordability through a stove subsidy (approximately $14)—has been critical in enabling local private-sector participation.

Financing targeted to the consumer has been a central feature of this business case. A results-based subsidy lowers the price of a stove for the household. Once CCL sells a stove at its subsidized price to an eligible consumer, it may recover the cost of the subsidy from the UNIDO programme. Since the stoves are relatively low-cost, at about $28 per unit, the subsidy, at about 50 per cent, is also relatively modest. This allows UNIDO to allocate funds to other types of support, including helping to underwrite marketing costs. A partnership with the Tanzania Investment Bank (TIB) provides a credit guarantee programme that can help leverage private investment. These mechanisms reduce business risk and address the affordability barrier that often constrains the uptake of a new cooking technology. In addition, the UNIDO programme offers training and technical support to strengthen local capacity among businesses, retailers, bankers, and government officials, providing the knowledge required to design and scale the market for a new cookstove and fuel (UNIDO, 2023b).

The UNIDO–CCL model highlights several lessons for the region. First, local companies can lead ethanol market development when provided with appropriate technical and financial support. Second, integrated value chains are valuable; stove assembly, fuel bottling, and retail distribution of stove and fuel must advance together to build trust and adoption. Third, consumer access depends on affordability and availability; low-cost goods and services, small-pack fuel sales, and familiar neighbourhood retail points are essential to reach typical urban households, whether middle- or lower-income.

As a business case, the Tanzania programme demonstrates how international partnerships and local SMEs can work together to create a viable ethanol cooking market. While not yet achieving the scale of KOKO's Kenya business, it shows a pathway for African markets to develop, creating opportunities for ethanol fuel, empowering local producers and distributors, and linking stoves and fuel to everyday consumer markets. With continued support and replication beyond Dar es Salaam, this model has the potential to transform how urban households access clean cooking fuel in Tanzania and other countries. More recently, UNIDO has engaged two additional distribution companies in Dar es Salaam that both compete and collaborate with CCL to expand coverage in the city, spurring competition and efficiency. As a result, the total number of ethanol stove user households is now approaching 30,000 and continues to grow.

2.5.3 ETHANOL COOKING IN REFUGEE CAMPS: A HUMANITARIAN INTERVENTION IN ETHIOPIA

Ethiopia hosted one of the earliest and most significant deployments of ethanol cooking in Africa, focused in part on refugee camps. Beginning in the mid-2000s, Project Gaia, in partnership with UNHCR, introduced the Cleancook stove and ethanol fuel to refugee camps in the Somali, Tigray, and Gambela regions. In the Somali camps, more than 12,000 stoves were distributed, eventually supported by bulk fuel storage facilities built in the camps, capable of storing 500,000 litres of ethanol (Tsehayu & Getaneh, 2016).

The intervention demonstrated that ethanol can completely replace firewood and charcoal in refugee camps when supply is well organized. Ethanol was delivered in bulk to the camp depots, stored in secured tank compounds, and distributed regularly to households using refillable jerry-cans. Training in the safe handling of fuel was conducted regularly. The Cleancook stove's non-pressurized design and spill-proof canisters, coupled with guidance on safe handling, ensured safety and ease of use, while the ethanol stove provided clean, smoke-free cooking.

The refugee programme in Ethiopia, which operated successfully for twelve years until funding for fuel purchases ceased in 2018, demonstrated several important lessons. First, large-scale distribution of ethanol in difficult and remote environments is feasible and can eliminate the need for wood and charcoal. Second, households quickly adapted to ethanol, reporting high levels of user satisfaction and improvements in breathing, eye irritation, and other conditions due to reduced smoke exposure. Third, the use of ethanol for cooking could be conducted safely, as the programme was virtually accident-free throughout its 12 years. Fourth, the programme highlighted the critical role of secure and continuous fuel supply. When fuel supply was consistent, the ethanol stove was used exclusively. When fuel was interrupted, households reverted to firewood. Since ethanol in Ethiopia is largely produced in government-owned sugar factories, cooperation with government was essential to supply ethanol fuel to the camps.

While designed as a donor-supported humanitarian initiative, the Ethiopian refugee camp experience provided a blueprint for supplying ethanol in commercial settings, whether in camps or in dense urban areas. It demonstrated that, with a reliable supply and an economical, "bare-bones" delivery system, ethanol is both safe and acceptable to households and can be delivered cost-effectively at scale.

2.6 Representative Technology Providers

2.6.1 CLEANCOOK STOVES

Cleancook Sweden AB, as a successor to the Swedish companies Electrolux and Dometic, has developed ethanol stoves for Africa and adjacent markets. Its stoves are designed to be simple, robust, reliable, and inexpensive to manufacture. They are intended to replace traditional biomass, kerosene, gas and LPG stoves. Their performance is close to that of LPG stoves and therefore offers a safe alternative to LPG. Electrolux first developed the underlying technology for this stove in the 1980s, having acquired it from a small Swedish company, ORIGO. The stove was designed to replace kerosene and LPG stoves on boats and in confined spaces, where a safer alternative than kerosene or LPG was needed. Electrolux pioneered the use of these stoves in Africa beginning in 2000. Cleancook Sweden AB assumed ownership of the stove line in 2011 and first set up manufacturing in Durban, South Africa, and then in Nairobi, Kenya. The Cleancook is the first ethanol stove of advanced design using liquid fuel to be manufactured in Africa.

The Cleancook stove operates with non-pressurized, spill-proof canisters, in which liquid ethanol is adsorbed onto the surface of and is bound up in a mineral fibre. The canister is designed to retain sufficient ethanol for a full day or more of cooking (approximately 4 hours at full power, or 1.2 litres of ethanol). The fuel canister is filled by hand and inserted in the stove. Ethanol vaporizes from the canister into a combustion chimney, where it mixes with air and combusts efficiently. This design avoids the need for frequent refilling and thus the need to handle liquid ethanol during cooking. It ensures safe, spill-proof storage of fuel in the stove. Cleancook stoves are easy to operate. Their sole moving part is an adjustable regulator that allows users to adjust vapour flow and flame size. Effective air intake and mixing in the combustion chimney ensure efficient combustion and high flame temperatures, approaching 900 °C. Cleancook stoves are built with a straightforward, economical design that enables local manufacture, ease of assembly and repair, and low-cost production. Their manufacture in East Africa and a competitive pricing strategy have helped make these stoves accessible to diverse markets, even without subsidy. The product line includes one- and two-burner models, with construction using aluminium, galvanized steel and stainless steel, or all-stainless-steel in the most durable models.

Stove production follows a flexible model that combines centralized manufacturing with regional partnerships for local assembly. Cleancook holds the tooling, patents, and technical designs, while manufacturing and assembly are contracted to partners. A key partnership has emerged with BURN Manufacturing in Nairobi, Kenya, which produces Cleancook stoves for the East African market. Stove kits can be shipped in flat-pack form and assembled in local workshops, including in refugee camps, to reduce costs and build local capacity. Fuel canisters can be shipped separately for use in locally designed and built stove bodies, provided these are approved by Cleancook for safety. To date, more than 130,000 Cleancook stoves have been manufactured and deployed across multiple African countries as well as locations in India, Viet Nam, Brazil, Haiti and Guatemala (Cleancook Sweden AB, 2025).



Figure 6: Cleancook products: two-burner model with aluminium body; all-stainless-steel one-burner with canister.

2.6.2 KOKO NETWORKS

KOKO Networks offers a two-burner ethanol stove, known as the KOKO Cooker, designed to operate with the KOKO fuel system. The stove is manufactured in India. It stores ethanol fuel securely in adsorptive fibre, similar to the Cleancook stove, and is equipped with burner regulators that allow adjustment of flame intensity for fast or slow cooking.

Uniquely, the stove is designed to connect to a refillable bottle that docks onto the stove using its SmartValve (a pin or needle valve) system to fill the fibre-packed fuel tanks within the stove. The fuel bottle is refillable at fuel vending machines called KOKO Points. These are ATM-style dispensing machines that also have the capability to function as referral stations for other products. They are placed inside neighbourhood shops. The bottle is docked to the stove or the KOKO Point upside down, using the pin valve to connect, and is filled or emptied through this valve. An NFC (Near-Field Communication) chip is imbedded in the bottle (referred to as “the canister” by KOKO) and communicates with the KOKO Point to identify the owner of the bottle. This allows KOKO to link the fuel sale to a specific customer and log each

transaction for record-keeping. This data is then available to KOKO for carbon finance monitoring and verification.

When fuel is dispensed from the bottle (canister) into the stove, it flows into a central tank and then, by capillary action, through fuel tubes into the fibre-filled tanks beneath the burners. The ethanol fuel evaporates from these tanks into the burners, supplying ethanol vapor for combustion. In this respect, the KOKO stove closely resembles the Cleancook stove.

A fuel return loop is built into the stove to return fuel from the fibre-filled tanks beneath the burners to the central tank in case the burner tanks become overfilled. This creates back pressure in the stove fuelling system that slows down or shuts off the filling of the stove through the pin valve. As a result, it is difficult to overfill the stove.

The dispensing of ethanol from the KOKO Point to the stove is therefore carried out in an enclosed system that avoids direct handling of ethanol, spills, or release of vapour. Since the bottle is filled and emptied in an upside-down position, vapour in the bottle is kept away from the opening. This provides an additional safety feature, since it is ethanol vapour, not liquid ethanol, that is flammable.

These design features of the KOKO stove make it somewhat expensive to manufacture, potentially difficult to maintain, and prone to failure, especially if the ethanol used in the stove is of poor quality, i.e., contaminated with distillation impurities. Although the cost of manufacturing the KOKO stove is not publicly disclosed, there is evidence that KOKO's internal manufacturing cost is about $100.

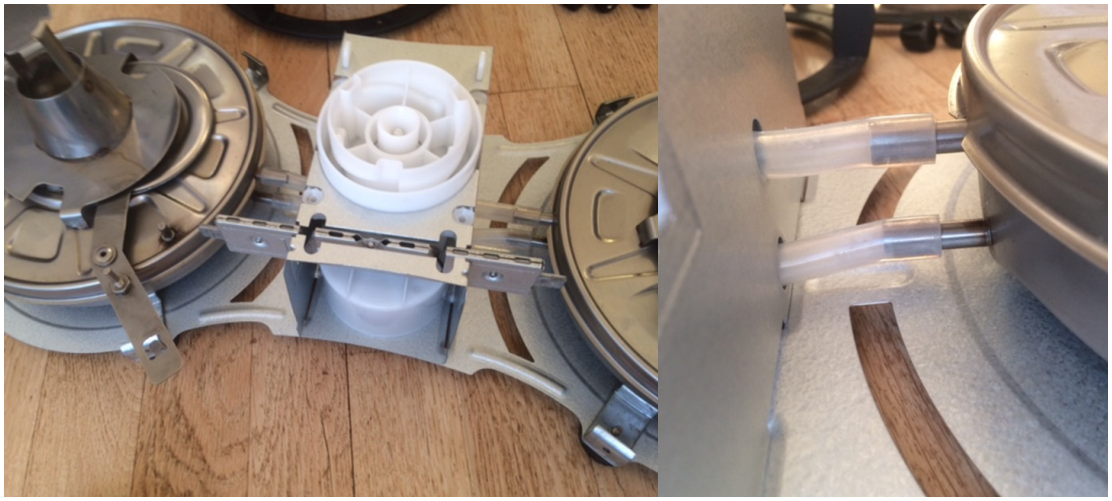


Figure 7: Burners, tanks, vapour pressure control system, bottle docking station, and locking mechanism in a partially disassembled KOKO stove. KOKO's system requires internet connectivity for cloud-based operations that monitor customer refuelling, fuel inventory levels at KOKO Points, restocking logistics, and payment transactions. These data can be used to support carbon credit verification. Smart MicroTankers replenish KOKO Points from centralized fuel depots, guided by routing and real-time data systems.

In 2025, KOKO reported that it was serving more than 1.3 million households across twelve cities in Kenya through its network of Smart Fuel ATMs. The company also expanded to Rwanda, where it reported that some 20,000 homes were being served in a commercial pilot project (MIGA, 2025).



Figure 8: KOKO products: KOKO Cooker with docked fuel bottle; KOKO Point with internet connectivity.

2.6.3 BLUE FLAME STOVES

The Blue Flame Stove, originally marketed under the brand name SAFI, is manufactured in China for the African market. It is a close copy of the Cleancook design but with a more contemporary appearance and the use of colour. The stove is marketed by a design firm in Norway, Abry & Kavanagh Design AS, which owns the product. The company provides both one- and two-burner models. The stove was developed around 2010, with the primary aim of generating carbon credits by displacing wood and charcoal stoves (Blue Flame Stoves, 2025b) (Green Development AS, 2025).

Like the Cleancook, the Blue Flame uses fibre-filled, non-pressurized canisters that adsorb the fuel and prevent spillage. The burners are equipped with ample wind screens to provide flame stability under draughty conditions. The stove's canisters are square with rounded corners and slide out for refilling. The canisters can be opened to allow replacement of the fibre medium should it become compromised from the use of poor-quality ethanol or other fuels, such as kerosene.

All metal components exposed to heat and flame are made of stainless steel, while the rest of the stove is manufactured from aluminium and painted mild steel. Blue Flame reports that over 55,000 stoves have been distributed in Kenya, Tanzania, and Madagascar under the SAFI brand. Nosy Maitso, the Malagasy company, uses the Blue Flame stove (Blue Flame Stoves, 2025b) (Nosy Maitso, 2026).



Figure 9: Blue Flame products: Blue Flame double-burner stove; Blue Flame single-burner stove with canister.

2.6.4 BUKONA AGRO GREENERGY STOVES

Bukona Agro Processors (Uganda) produces the "Greenergy" bio-stove. Manufacturing currently takes place in India, with plans to relocate production to Bukona's distillery site south-west of Gulu in northern Uganda. An estimated 25,000 stoves are in use in 11 cities in Uganda, including 7,000 stoves in Kampala, and a small number of these stoves are in use in Dar es Salaam, Tanzania. Bukona Agro supplies ethanol for its own stoves and sold ethanol to KOKO Networks in Kenya when it was operating. The company sells single- and double-burner stoves (Kekal, B., Bukona Agro Processors Ltd., online interview, Dec. 8, 2025).

The Greenergy stove, like the Blue Flame, is a close copy of the Cleancook, with stylistic innovations. It operates using ethanol adsorbed into a fibre-filled canister and vaporized into a combustion chimney. The canister slides out from the front of the stove for refilling. A regulator at each burner controls flame size. The stylistic design and choice of materials add appeal as well as some cost to the stove.

Bukona Agro offers a pressure cooker with the stove and actively promotes its use by bundling purchase of the pressure cooker with the stove. Bukona states that the pressure cooker can reduce fuel consumption by 70 per cent (Bukona Agro Processors Ltd., 2025a). It plans to include the pressure cooker into its carbon finance methodology.

Bukona integrates stove supply with the sale of its ethanol, marketed as “Greenergy Bio-fuel”, which it produces in its cassava-based distillery. In this way, Bukona Agro has created a vertically integrated business model linking stove distribution with fuel production. This vertical integration is a favourable development for ethanol stove markets. Sunbird Bioenergy in Zambia, a new cassava distillery project, is considering a similar strategy (Bukona Agro Processors Ltd., 2025a) (Sunbird Bioenergy, 2026).

Uganda remains heavily dependent on charcoal for cooking, and deforestation linked to charcoal production is widespread. Bukona Agro promotes its stove and pressure cooker combination as a cleaner and more efficient alternative to charcoal, and intends to pursue carbon credits based on these performance gains. President Museveni and the Government of Uganda are supportive both of fuel blending and ethanol stoves. Ugandan standards for both stoves and fuel have been enacted (Uganda National Bureau of Standards, 2026).

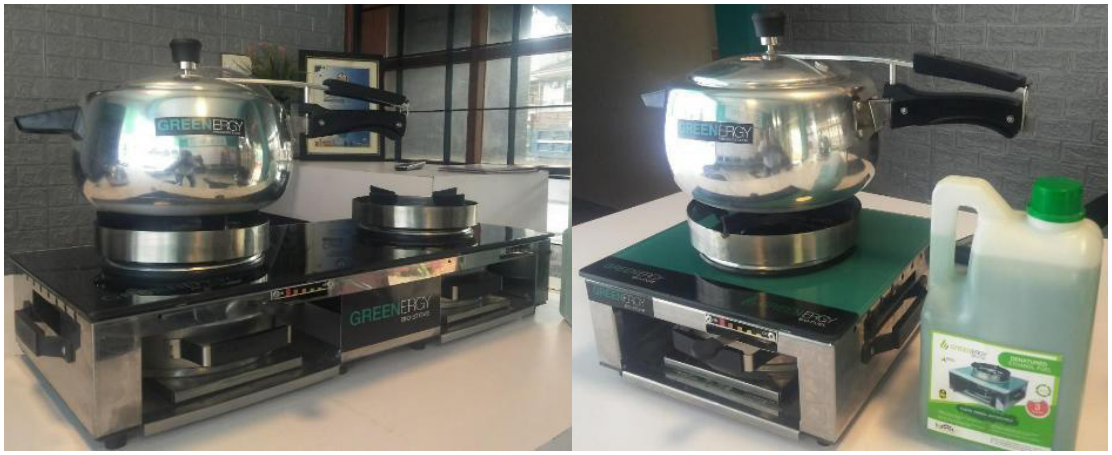


Figure 10: Greenergy products: Greenergy two-burner stove and pressure cooker; Greenergy one-burner stove and fuel (Uganda Development Corporation, 2023).

2.7 Overview of Current Market Development in Sub-Saharan Africa

Ethanol cooking markets in SSA are advancing unevenly, yet a clear picture is emerging of what works and what remains challenging. The most advanced examples —Kenya, Tanzania, Ethiopia, Madagascar, Nigeria, and Mozambique—show that scale is possible when stove distribution and fuel supply are paired with reliable delivery systems, consumer finance, and conducive government policy. Carbon finance is helpful, especially in reducing the purchase price of the stove, but it must not be the sole source of revenue for the project; the project must make business sense without carbon finance—even if its absence results in slower uptake. Other countries, such as Rwanda, Uganda, and Ghana, are at earlier stages of ethanol cooking, but their commercial pilots and ethanol fuel supply potential signal readiness for larger-scale development if enabling conditions fall into place.

Until December 2025, Kenya stood out as the continent's most advanced ethanol cooking market. Certainly, in practice it was. KOKO Networks had prompted over one million households to shift, at varying degrees, to ethanol, supported by competitive pricing and a platform that placed neighbourhood refill kiosks close to millions of consumers. KOKO demonstrated how urban demand can be tapped at scale by combining technology, logistics, and carbon finance to make ethanol both affordable and convenient. This model can be replicated in urban markets across Africa, but only if governments work with businesses to assure that there is an adequate supply of ethanol, whether imported or locally produced, and that fiscal policies are reformed to treat ethanol fairly so that it is affordable, i.e., competitive with other purchased fuels such as charcoal and LPG.

Tanzania offers a strong and perhaps the most sustainable case with the UNIDO-sponsored rollout of Cleancook stoves in Dar es Salaam, where Consumer's Choice Limited (CCL), a local company, has taken responsibility for stove procurement, wholesale fuel purchase, local assembly, bottling, supply, and retail fuel distribution, all with its own capital, aided by measured, performance-based incentives from UNIDO, but not by carbon finance or venture capital investment from abroad. By linking fuel supply to an existing fast-moving consumer goods (FMCG) distribution network, CCL has made ethanol available through local retail outlets. The programme highlights how a local Tanzanian business, when provided with

technical support and general facilitation, including engagement with government to create an enabling environment, can deliver stoves and fuel on a commercial basis to thousands of households in a major city. CCL does plan to develop carbon finance for its business but, as an SME, must raise capital internally to support this. Once the UNIDO-funded stove subsidies are no longer available, carbon finance will take over as the source of funds to subsidize the stoves.

Ethiopia has the longest history of ethanol cooking programmes in Africa. Beginning in 2005, Cleancook stoves, originally from Sweden, were deployed in refugee camps, displacing firewood and reducing household air pollution. More than 12,000 stoves were distributed under UNHCR-supported programmes in several refugee camps. Ethanol fuel was available in these camps, with several interruptions, through 2018. A large pilot study was also conducted in Addis Ababa, reaching more than 2,000 households, and a limited commercial supply of ethanol and stoves remained available through 2020, when most state-owned ethanol production shut down for various reasons. The Ethiopian experience shows both the promise and the risks. Ethanol can completely transform cooking, but the lack of adequate production and a consistent fuel supply is a major barrier to success, especially given the very limited regional or international trade of ethanol in Africa (Rogers, Sovacool, & Clarke, 2013). The work conducted in Ethiopia, however, has been instrumental in the spread of ethanol cooking to other countries in Africa.

Uganda represents a newer and very promising model. Bukona Agro Processors produces starch-based ethanol at a distillery in the north of the country, relying on cassava and corn, and has taken on management of the entire value chain, from fuel production to stove manufacturing, distribution, and sales, including direct household fuel delivery. The integration of consumer finance through banks and donor-backed subsidies is helping to make Bukona's stoves affordable for low-income households. Like CCL, Bukona hopes to establish a carbon finance programme. But the business must be on sound footing first. The Uganda example demonstrates how a vertically integrated approach can address supply, reliability, and consumer confidence, while achieving economies of scale in vertical integration (Bukona Agro Processors Ltd., 2025b) (Demekas, Miller, & Pirelli, 2025).

Because African countries typically insist upon locally made stoves and enforce trade barriers to discourage imported ones, Bukona Agro is moving its stove manufacturing from India to its plant in Uganda. This will reduce the tariff and freight burdens on the stoves. Bukona Agro is also embarking on fuel blending to support the country to achieve its 5 per cent blend target. Bukona plans to scale up ethanol production, equip its plant to produce anhydrous ethanol (essential for gasoline fuel blending), and has obtained a government license to build one of four blending depots to supply E5 gasoline for the nation (The Independent, 2025) (Wafula, 2025).

Rwanda has only recently joined the countries engaged in ethanol cooking by proactively enacting policies to attract market participants and support ethanol fuel. In a commercial pilot, KOKO Points are serving more than 20,000 households in Kigali as part of the government's commitment to clean cooking solutions nationwide. Rwanda could become an example of how smaller markets can leverage existing commercial models to rapidly transform their markets (FAO, 2024). However, given KOKO's decision

to close in Kenya and the fact that Rwanda does not have a domestic ethanol industry but must import ethanol from the region, it is unclear how KOKO will succeed in Rwanda, even if the government cooperates in issuing Article 6 carbon credits to meet KOKO's need for subsidies.

Other countries remain at earlier stages of development but show potential. A business in Madagascar, Nosy Maitso (translated from Malagasy as "Green Island"), has moved from years of pilot studies to a growing commercial business. It has some 35,000 ethanol stoves in operation. Because Nosy Maitso experienced persistent difficulty in buying ethanol from existing sugar factories or importing it, it developed the know-how to produce ethanol in entirely locally built, efficient micro-distilleries. This was the approach recommended in a World Bank ethanol fuel cooking study published in 2011 (World Bank Group, 2012). Nosy Maitso has built several micro-distilleries and has a plan to build many more to produce cooking fuel in local markets. Given Madagascar's terrain, road network, great distances between markets, and the predominance of small-scale agricultural production, the micro-distilleries may offer the best solution for assuring fuel supply. By linking micro-distilleries with a stove fuel market, vertical integration is achieved, and both the producer's and consumer's risk —one of demand and the other of supply— are reduced.





Figure 11: Nosy Maitso's first fuel ethanol micro-distillery, built in Antananarivo and installed in Vohipeno, in the Fitovinany region, along the Indian Ocean coast. This micro-distillery commenced production in June 2023. (Photo: Eirik Sandstø).

Nigeria has very substantial ethanol production potential both from cassava and sugarcane. It is also a significant importer of crude ethanol. Numerous pilot studies and several commercial start-ups have successfully tested ethanol stoves and fuel distribution in urban markets. However, the link between ethanol production in Nigeria and household fuel is still weak. Ethanol producers have done little to help stove businesses get off the ground, remaining attached to their traditional markets—mainly the beverage trade. As a result, ethanol stove businesses in Nigeria suffer from a lack of good-quality ethanol. Moreover, the price of ethanol for cookstove fuel is unduly affected by the hard currency exchange rate of the Naira. This affects the cost of imported ethanol, which, in turn, affects the cost of domestically produced ethanol. Several ethanol stove pilot studies have been conducted in Nigeria, both in the North and the South, and several commercial businesses are running (Ozier, ***et al.***, 2018) (Hinata Energy, 2025). However, the government's clean cooking priorities are mostly focused on expanding the use of LPG, even though this remains almost exclusively an imported fuel. Consequently, ethanol cooking has largely been left to find its own way, without any meaningful government support.

Mozambique has abundant feedstock and a large base of sugar production but, so far, despite several attempts, no sizeable distilleries are operating. It has been difficult to attract large project investment in Mozambique. KOKO Networks first began in Mozambique as CleanStar Mozambique Lda. (CSM) in 2012 (Clean Cooking Alliance, 2025). They used Cleancook stoves, manufactured in Durban, South Africa. Cleancook ethanol stoves were rapidly taken up in Maputo, reaching some 31,000 homes by the end of the first year of operation, but scale-up faltered due to the lack of domestic ethanol supply. CleanStar eventually closed and moved to Kenya, reorganizing as KOKO Networks. A second commercial start-up in Mozambique, YAZU, faltered for the same reason. Mozambique remains a promising market for ethanol stoves once there is sufficient local production of ethanol. The Government is actively pursuing ethanol blending in transport fuels, which could provide economies of scale for cooking if linked to consumer-facing distribution business (Club of Mozambique, 2024) (IEA, 2025).

Taken together, these cases show that SSA already has a foundation for an ethanol cooking market, but one that needs continued effort—particularly in support of ethanol-fuel-friendly policymaking. Success will depend less on technology, which is still evolving but already well developed, and more on creating a reliable fuel supply, facilitated by investment and fiscal and trade policies, and supported in some measure by affordability mechanisms like carbon finance and those offered in the UNIDO programme to promote the dissemination of stoves. Where ethanol fuel policy is being developed, albeit unevenly, there is progress, as in Kenya with its fuel kiosks, Tanzania with its FMCG model, Ethiopia with its refugee camp successes, and Uganda with its integrated producer-retailer model. Where ethanol fuel has entered the market, it has demonstrated the ability to displace solid biomass, kerosene, and even LPG fuels for cooking. Countries with strong agricultural production bases, such as Nigeria and Mozambique, or emerging commercial footholds, such as Rwanda and Ghana, can join the frontrunners if they advance in policy, fuel supply, and retail systems.

Table 3: Summary of ethanol cooking markets by country.

Country	Current Status	Scale/Reach	Distribution Model	Fuel Supply
Kenya	Most advanced retail deployment by several companies, led by KOKO	Over 1.3 million households reached but now left unserved by KOKO's retreat	Smart distribution system using ATM-like refill stations in neighbourhood shops where customers refill canisters; closed container system	Imported and locally produced ethanol stored in depots and moved via micro-tankers to petrol stations and then on to retail dispensers in shops
Tanzania	Advanced urban rollout under UNIDO and UNCDF programmes	About 20,000 stoves in Dar es Salaam; slow but steady growth	Consumer's Choice Ltd. assembles stoves, transports and bottles fuel, and uses FMCG distribution	Local and regional ethanol supply and bottled ethanol distributed to small shops and kiosks in neighbourhoods
Ethiopia	Humanitarian and commercial pilot deployments	Over 12,000 stoves in refugee camps and 2,500 in Addis Ababa	Organized storage and distribution in camps via UNHCR with centralized bulk storage	Local ethanol supply from state-owned sugar factories trucked by Gaia, UNHCR's implementing partner
Madagascar	Transitioned from pilots to commercial enterprise; received support from World Bank Ci-Dev carbon finance programme	About 35,000 stoves in urban/peri-urban areas	Local stove sales and retail fuel shops	Bottled fuel initially from imports, now from domestic micro-distilleries erected by the stove business; plan to expand number of micro-distilleries

Country	Current Status	Scale/Reach	Distribution Model	Fuel Supply
Uganda	Vertically integrated producer-retailer producing ethanol from own feedstock and producing and selling stoves	Stoves are being sold in Kampala and other Ugandan cities, as well as in Dar es Salaam	Bukona Agro manufactures stoves, produces ethanol, and delivers fuel weekly directly to homes, with mobile tracking	Cassava-based domestic ethanol; plans for expansion and use of corn to increase feedstock production and supply
Rwanda	Early commercial foothold supported by strong government policy support	20,000+ subscribing households since 2023	Smart distribution system using ATM-like refill stations in neighbourhood shops where customers refill canisters (as in Kenya)	Centralized storage serving retail shops in Kigali. Fuel coming from neighbouring countries (Kenya, Uganda, Tanzania)
Nigeria	Pilot testing conducted in both South and North and in Lagos since 2007; several commercial start-ups running	Commercial stove and fuel distribution businesses; fuel is obtained from crude ethanol imports and several domestic distilleries	Retail packaging and shop-based trials. Scale and penetration are limited by the cost and quality of the ethanol available	Cassava- and sugar-based production capacity still needs to be developed, but the potential is great. Nigeria is the largest ethanol importer, but imports are largely for industrial use and beverage production
Mozambique	Ethanol supply-limited with several commercial pilot activities. Government has interest in blending	Early commercial attempts mostly in Maputo and Matola	Retail shops linked to depots and road networks. Ethanol sold in bottles	Large sugarcane/ molasses base but no sizeable distilleries yet, although several planned

2.8 Key Considerations for Promoting Ethanol Cooking Market Growth

Ethanol cooking offers a clean, renewable, and scalable solution that can reduce reliance on traditional biomass, improve public health, and contribute to national and global climate goals. With the right enabling conditions, the sector can move beyond small-scale commercial pilots to develop into a robust and dynamic market, delivering tangible benefits for households, communities, and entire economies. Achieving this vision is not automatic: it requires coordinated action across multiple fronts, including cookstove and fuel standards, conducive trade and taxation policies, fuel supply security, fuel handling infrastructure, finance, consumer engagement, institutional alignment, and, ideally, integration into a nation's broader energy and climate policies.

2.8.1 STANDARDS, REGULATION, AND LEGAL CLASSIFICATION

The foundation of any successful fuel market is clear, measurable standards. For ethanol, this means not only distinguishing among alcohol products but also specifying the purity levels of the fuel and the performance, durability, and safety requirements for stoves. National standards authorities have made substantial progress in aligning ethanol standards with global benchmarks, such as those provided by ASTM and ISO (ASTM, 2024) (ISO, 2020). Ethanol fuel and stove standards have been adopted in Kenya, Uganda, Tanzania, Rwanda, Mozambique, and Zambia (SNV, 2019) (UNBS, 2016) (TBS, 2025) (RSB, 2024) (ERB, 2022). The Economic Community of West African States (ECOWAS) has adopted draft standards for its region (ECREEE, 2021). Most countries have adhered closely to the ASTM E3050 standard on ethanol cooking fuel. Once standards are adopted, they must be reinforced through national regulatory frameworks and enforcement mechanisms.

Effective market surveillance and conformity assessment systems are essential to prevent substandard or unsafe products from entering circulation.

Establishing a standard for ethanol cooking fuel also enables the legal classification of ethanol that has been properly denatured, marked, and packaged for household use. In countries without ethanol fuel standards, ethanol is treated as an industrial chemical or beverage precursor, attracting high excise duties and regulatory restrictions. Using this ethanol as fuel creates an uneven playing field, where ethanol must compete with tax-advantaged LPG and other fuels like charcoal that may not be taxed. Correct classification and reasonable fiscal policy parity for ethanol with other fuels are therefore essential to make ethanol fuel competitive. Regional harmonization strengthens market confidence, allowing producers to move fuel and appliances across borders without excessive fees, repeated testing, or administrative delays.

2.8.2 SUPPLY SECURITY AND DOMESTIC PRODUCTION

A dynamic ethanol cooking market cannot exist without a reliable supply of fuel. Households are understandably reluctant to adopt new stoves if they fear that fuel will not be consistently available at predictable prices. Ethanol cooking start-up businesses have often struggled with the "chicken or egg" dilemma: without fuel there is no demand, and without demand, fuel producers are unwilling to invest in production and distribution. Breaking this impasse requires pragmatic solutions.

In the early stages of market development, strategic imports can ensure availability and reassure consumers. Importing ethanol from established producers in neighbouring countries or from global exporters such as Brazilian and American producers can provide guaranteed supplies while the domestic sector builds capacity. The main barrier to imported ethanol is the cost of import and excise taxes, which are typically high. Denatured ethanol for fuel use must be allowed to qualify for lower taxes, such as those set for imported petroleum fuels. Over time, local production can be encouraged to ensure domestic supply. Feedstocks such as molasses, cassava, sweet and grain sorghum, and various agricultural residues are widely available across Africa, and many projects have already demonstrated their viability. Establishing small and micro-distilleries in farming communities offers a practical solution, often easier to implement than constructing large-scale facilities. Micro-distilleries offer the dual benefit of creating rural employment and reducing transport costs. They may be locally owned and financed. Larger integrated facilities, often associated with sugar mills, can serve large, urban markets and support national programmes, while micro-distilleries may be better at serving local markets in rural communities (UNIDO, 2024).

Diversification of feedstocks is beneficial and contributes to sustainability. Building a national ethanol fuel programme on cassava in addition to sugarcane is one example. The development of micro-distilleries may encourage the use of alternative feedstocks, such as cashew apple, a residue from the cashew nut industry, since these distilleries

can be sized to match feedstock availability. Over-reliance on a single feedstock exposes ethanol fuel supply to fluctuations in crop yields, prices, or competing demands from the food and beverage industries. Policymakers and investors are advised to guide development towards a balanced portfolio of raw materials, with appropriate safeguards for food security, the environment, and land use (UNIDO, 2015).

2.8.3 INFRASTRUCTURE AND DISTRIBUTION

Even when ethanol is produced in sufficient quantities, the challenge of delivering it safely, cheaply, and efficiently to households remains. As a liquid fuel, ethanol can leverage existing infrastructure such as storage depots, road tankers, and retail distribution systems. Kerosene infrastructure can be repurposed to handle ethanol. However, ethanol has specific handling requirements that must be respected. In many settings, modular storage solutions and small-scale packaging tailored for household use may be the best solution.

Developing national or sub-regional supply hubs can stabilize distribution, particularly in landlocked countries. Port states can act as entry points for imported ethanol, with onward distribution coordinated through road and rail networks. At the local level, ensuring safe last-mile delivery requires investment in retail infrastructure, training for vendors, and clear labelling of certified products. These systems should be fully regulated. Such measures build consumer trust and protect early adopters from counterfeit or unsafe fuel.



2.8.4 FINANCING: HELPING BUSINESSES AND HOUSEHOLDS

The issue of finance is relevant to all levels of the ethanol fuel value chain. For low-income households, the upfront cost of an ethanol stove can be a deterrent, even if the long-term savings on fuel are attractive. Access to credit, pay-as-you-go systems, or results-based subsidies can bridge this gap. For example, donor-supported programmes that reimburse suppliers once stoves are sold and verified in households can lower costs for end-users while incentivizing suppliers to expand their distribution. UNIDO has used this approach in Tanzania.

Ethanol cooking directly reduces greenhouse gas emissions compared to traditional biomass or kerosene (UNIDO, 2023c). If these reductions are quantified, verified, and sold as carbon credits, the additional revenue can make projects more financially secure. Streamlined methodologies and monitoring systems for ethanol cooking already exist. Aligning carbon finance with international disclosure standards reassures investors and helps integrate ethanol projects into broader climate strategies. This is required for moving from the voluntary carbon market to the more regulated Article 6 market, where carbon credits are likely to be more valuable (UNIDO, 2023c).

2.8.5 GOVERNMENT PILOTS AND EVIDENCE BUILDING

Governments have a critical role to play in moving from planning to implementation, including the adoption of policies, regulations, and investment rules. Over the past 20 years, pilot programmes—whether in specific cities, institutions such as schools and hospitals, or refugee camps—have provided the evidence base needed for adoption. In areas new to ethanol fuel, well-designed pilots can demonstrate ethanol's many practical benefits, including faster cooking times, reduced indoor air pollution, easier and safer handling, and lower household expenditure compared with charcoal or LPG. These pilot studies should be rigorously conducted, with findings shared transparently to inform investors who will be responsible for scale-up.

2.8.6 CONSUMER AWARENESS AND TRUST

No market can succeed without consumer confidence. Households need to know not only that ethanol stoves and fuel are available, but also that they are safe, reliable, and affordable. Public awareness campaigns, community demonstrations, and training sessions are essential. Clear labelling of certified stoves and fuel reassures consumers that they are purchasing genuine products.

At the same time, authorities must crack down on counterfeit or unsafe products, which can quickly undermine trust.

2.8.7 INSTITUTIONAL COORDINATION AND CAPACITY

Stimulating ethanol market growth requires coordination across multiple government agencies. Ministries of energy, environment, agriculture, health, finance, trade, and standards must align their efforts rather than work in isolation. Inter-ministerial task forces or national clean cooking councils can provide a platform for collaboration. At the regional level, coordination efforts can bring together governments, donors, and private sector actors to harmonize standards, align incentives, and monitor progress. Building institutional capacity at the national level is also essential. Laboratories, customs officials, and inspectors all require training to understand the properties and requirements of ethanol fuel and to ensure even-handed enforcement.

2.8.8 POLICY INTEGRATION AND INCLUSIVE GROWTH

A dynamic ethanol fuel market must be integrated into broader policy objectives. Ethanol should be explicitly included in national energy strategies, climate commitments under the Paris Agreement, and fiscal policy documents. This encourages consistent treatment, budget allocations, and stability for long-term investment. Inclusive policies can ensure that growth benefits all segments of society. Low-income, rural, and displaced populations should be included, and women-led enterprises should be supported throughout the value chain.

Underlying all these efforts is the need for reliable data systems. Data on production, distribution, prices, sales, user experience, health outcomes, and carbon impacts should be collected and shared. Transparent data builds confidence among policymakers, donors, and investors, and allows progress to be tracked. Without such data, planning, financing and accountability will remain weak.



3

SOLID BIOMASS FUELS FOR GREEN COOKING

CHRISTIAN RAKOS
(WORLD BIOENERGY ASSOCIATION)



3.1 Introduction to the Technology

Using upgraded solid fuels for green cooking has a number of advantages. There is an abundance of solid biomass that is currently largely wasted—being burned in the fields, landfilled, or simply left to rot. Upgrading solid biomass to clean-burning fuel requires only physical processes, which can be implemented with relatively low investment and small amounts of energy.

Only two main processes are required: drying and mechanical treatment. **Drying** is necessary unless the biomass is already dry, as in the case of straw or rice husks. Drying can be achieved naturally, by spreading biomass in the sun, or through forced drying, for example using rotating drum driers that employ biomass as fuel to generate hot air. **Mechanical treatment** is required to create a homogenous, reasonably dense fuel. If the raw material has a high density by itself (e.g., nutshells, palm kernel shells, wood, bamboo), chipping or crushing—and possibly sieving—may be sufficient to produce a dense, homogenous fuel. These technologies are simple and incur very low investment, energy, and operational costs.

If the raw material is less dense (e.g., sawdust, straw, rice husks, bagasse, peanut shells), it must be dried (if humid), milled and densified. For domestic cooking fuel, densification into pellets is significantly better than densification to briquettes, as pelletised fuel burns much more cleanly and efficiently in gasifying stoves. Dry husks can be directly used as fuel also with special purpose stoves (Kole *et al.*, 2022).

Pelleting plants range from small-scale operations producing a few tonnes per day to larger industrial plants capable of producing 100 to over 1,000 tonnes per day. Investment costs for establishing pellet production infrastructure can vary significantly, depending on the humidity and nature of the raw material, as well as local circumstances such as building costs and electrical connections.

A wide range of technologies is available to convert upgraded solid biomass into useful heat efficiently and cleanly. At the household level, gasifying cookstoves provide smoke-free cooking (Scharler *et al.*, 2021) that is cheap, efficient, fast, and convenient. An important advantage of upgraded solid biomass is that it can also be used in larger cookstoves for institutional or commercial cooking, as recently demonstrated in Rwanda by the World Bioenergy Association in cooperation with the local pellet producer BioMassters (Roelofs, 2025).

Upgraded solid biomass fuels can also be used in commercial and industrial

applications, as a wide range of burners and boilers are available for every scale of operation—from a few kilowatts of output to full power plant capacity. This is important because commercial and industrial users can create the necessary fuel demand for newly established pelleting plants or chipping operations.

In general, heat generation with upgraded solid biomass can be highly efficient, cost-competitive, and substantially cheaper than fossil fuels or electricity, both for domestic cooking and industrial operations. Nevertheless, the initial projects attempting to introduce pellet cooking in SSA encountered a number of challenges (Mulenga and Roos, 2021), (Bailis and Wanjiru, 2018), (Lambe, 2020). These studies discuss the various issues that made pellet cooking projects difficult during the early phase of deployment. These begin with unreliable pellet supply. The high upfront cost of a pellet cookstove can hardly be justified if fuel availability is in question. Small pellet producers encountered a variety of difficulties in producing fuel reliably and, in some cases, such as in the early pilot projects in Kenya, no domestic pellet production existed.

Another issue mentioned in various studies is the availability (and affordability) of repair services. Due to their electric components, stoves can fail, and early models had considerably high failure rates. An intrinsic issue with most early pellet cookstove models is the lack of regulation of output power, so stoves are not suitable for long-term simmering needed for some foods such as beans. Also, most pellet cookstoves cannot be recharged without emptying the embers and refilling and reigniting the stove, which differs considerably from charcoal stove operation.

Many of these issues have been addressed in the meantime. Bailis *et al.* (2020) report satisfied customers, but also continued stove stacking. New stove models such as the Ecosafi stove offer excellent power regulation and long cooking times. The Gasio range of stoves allows users to recharge during operation and offers very good control of output. Reliability of stove operation has also improved, and Zulu *et al.* (2024) report very high customer satisfaction in a case study in Malawi, with 91 per cent of pellet stove users expressing high satisfaction. The main advantages reported are increased cooking speed and lower fuel consumption. Domestic pellet production has become more reliable and consistent, although sufficiently large markets with several competing producers are still missing due to a lack of supporting policies and, consequently, a lack of offtake.

3.2 Technologies to Produce Upgraded Solid Biomass

3.2.1 PELLET PRODUCTION

Agricultural production, crop processing, forestry, and wood processing generate large amounts of biomass that are difficult to use due to their low density and variable moisture content. The pelletization process is a three-step method that can transform these residual materials into a valuable fuel.

Step 1: Drying

The first step is drying the raw material—unless it arrives already in dry conditions. Pelletization only works if the water content of the raw material is below 15 per cent. In many current pellet production facilities in SSA, this step is either not included or poorly equipped, leading to frequent problems with pelletization. A continuous pelleting process with consistent quality output depends on precise control of moisture, which should not vary by more than 1-2 per cent. Pelleting plants that rely solely on natural drying or on heat generated by burning firewood can hardly achieve this level of precision. A heat source that uses automatic fuel feeding, e.g. using wood chips, is needed to ensure a stable drying process.

Step 2: Milling

The second step is milling the material, usually performed by a hammer mill. It is essential that strong magnets and stone traps are used before the dry biomass enters the mill, as steel parts or stones cannot only damage the machinery but also create sparks that may ignite dust explosions or fires. Fire prevention is critical, as dry biomass dust is highly inflammable, and a large number of fires and explosions have occurred in pelleting plants around the world.

Step 3: Conditioning and Pelletizing

The milled, dry raw material may be mixed with additives such as starch or sprayed with small amounts of water to adjust moisture and facilitate pellet formation. This conditioning step will depend on the type of biomass and is typically applied when wood residues are pelletized, but may not be necessary for agricultural raw materials.

Finally, the raw material enters the pellet mill, which presses it through holes in a steel die to densify it. Dies can be flat steel plates or rings with multiple holes. Rollers press the raw material through the die, generating frictional heat, so pellets have to be cooled after they exit the mill. Once cooled, pellets can be packaged in bags or loaded in bulk to trucks for transport to commercial customers.

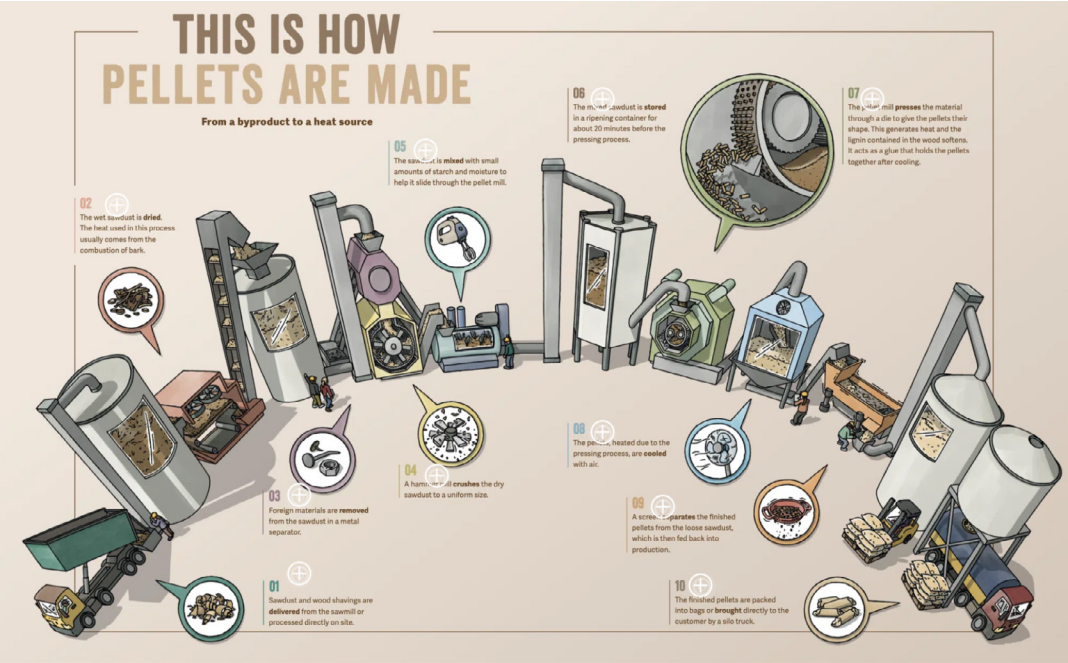


Figure 12: Overview of the pellet production process.

3.2.2 INVESTMENT NEEDED FOR PELLET PRODUCTION INFRASTRUCTURE

It is difficult to obtain consistent data on the cost of pellet production infrastructure, as equipment prices vary significantly depending on production capacity, technical specifications, and local factors such as building and infrastructure costs.

With respect to production capacity, small-scale pelleting plants with a capacity of a few 100 kg of product per hour need to be distinguished from industrial-type equipment that starts at capacities of 2 t per hour. Small-scale plants can be realized with a budget of approximately $100,000 investment. However, it is disputed among experts whether small-scale plants can operate consistently and produce quality pellets over a significant number of operating hours. For an industrial-size plant, an investment of $1-2 million for a production capacity of 15,000 tonnes per year can be expected. Considering that this capacity would suffice to produce cooking fuel for approximately 150,000 people, it becomes clear that pelletization is relatively inexpensive, requiring an investment in fuel manufacturing of about $7-14 per person served. Obviously, that scale of production would require a significant existing cookstove market or considerable commercial offtakers of fuel.

The production capacity of pellet mills is usually described in terms of output per hour. Annual production capacity is consequently a function of operating hours, and experience shows that many pellet plants in SSA do not achieve sufficiently high operating hours for various reasons, such as inadequate equipment, intermittent electricity supply, lack of raw materials, lack of offtake, etc.

There are considerable differences in both price and quality among equipment manufacturers. Transport of equipment, import tariffs, land acquisition, buildings, storage, and infrastructure can add significantly to overall costs, sometimes exceeding equipment costs. Given these variations, and the tendency of some operators to "save" by omitting essential components (e.g. drying systems), purchasing pellet production equipment is risky for inexperienced buyers.

It is strongly recommended to involve experienced planners in the procurement process. Partnering with an experienced joint venture partner that has already been producing pellets for some time would be even better. Turnkey contracts also offer a safer way of investing than buying cheap equipment from various suppliers or purchasing a pellet plant FOB and then struggling with assembly, missing parts, lack of qualified engineers, etc.

3.2.3 CHIPPING, CRUSHING AND SIEVING

Chipping

Chipping is a technology used to produce a homogenous fuel from wood and wood residues that is more widely used and older than pelletization. Sharp knives mounted on rotating disks or drums cut wood, branches, bamboo, and similar materials into small pieces, typically a few centimetres in size. Chipping is also commonly used to prepare wood for the production of pulp and paper or for various types of particleboards.

The use of wood chips instead of pellets could represent an important stepping stone in establishing an African clean cooking economy based on solid biomass. Gasifying stoves also perform well with dry wood chips. However, they need to be larger to accommodate sufficient fuel for the required cooking times, as chips have a lower energy density. Chips are much easier to produce than pellets and require an upfront investment for fuel production that is significantly lower. Chip production presents an opportunity for those working in the charcoal supply chain to continue their business by upgrading from carbonisation to chipping technology.

Jacobson and Ciolkosz (2022) show that even producing pellets from short-rotation forestry would yield lower costs than charcoal production, assuming that the wood is chipped and subsequently pelletized. Without the heavy investment in a pelleting plant, wood chips would be even more competitive, provided the right equipment is used.

Both stationary and mobile chippers are available. Mobile chippers can be moved to raw material, which is left to dry along forest roads before chipping in Europe. They can either be tractor-pulled or equipped with their own diesel engine.

In an African context, a stationary electric chipper powered by photovoltaic (PC) electricity could be a robust solution, offering lower operating costs and reduced maintenance compared with diesel-power alternatives.

The quality of wood chips as fuel is directly related to their moisture content. Only dry chips with a water content below 20 per cent are considered high-quality fuel. Achieving this requires adequate time for natural drying of raw material or subsequent drying of chips after chipping. Drying raw material before chipping usually takes longer than drying the chips themselves. Also, wood or bamboo are easier to chip while still moist. Chips can be spread out in the sun for a few days, with frequent turning to ensure uniform drying. It should be noted that chips in piles dry very slowly and can degrade due to mould formation, which poses a health hazard, so spreading them out in the sun is important.

Sieving

The particle size distribution of chips depends on the raw material and the chipper setup. Domestic gasifying cookstoves require chips of small, uniform size, typically 2-4 cm. Too large pieces or an excess of fines can affect combustion negatively. This can lead to the necessity of sieving the chips before marketing. Rotating drum screens are well suited for this purpose.

Properly sized chips not only enhance combustion efficiency but also produce quality charcoal as a residue from cooking. This charcoal can subsequently be extinguished and sold or used as soil enhancer. Fines separated by sieving can serve as raw material for pelletization.

Crushing

Hard residues, such as diverse nut shells or palm kernel shells, may require crushing to increase their density and make them suitable for use as cooking fuel. The best approach is to test their suitability as they arrive in different cookstoves and determine the required degree of crushing based on combustion behaviour and burning time until a satisfactory result is achieved. In some cases, a combination of crushing and screening may need to be considered to optimize results.

3.3 Technologies for Clean Cooking with Upgraded Solid Biomass and Brief Overview of Technology Providers

3.3.1 TECHNOLOGY BRIEF

Gasifier cookstoves convert solid biomass into a combustible gas that burns without generating smoke, representing the cleanest and most efficient method for using solid biomass as fuel. This is achieved by splitting the combustion process into two zones. In the first zone, the solid biomass is converted into combustible gases. In the second zone, these gases are combusted with preheated air, producing a clean-burning gas flame. The oxygen supply is carefully controlled to ensure complete and efficient combustion. A controlled airflow is essential, which can best be achieved with a small fan—hence the term "forced-draft gasifying stove."

The stove contains an inner metal cylinder, the combustion chamber, which has an open top and air inlets at the bottom and near the top. This cylinder is enclosed by another cylinder, leaving a gap for air to pass through. The fan drives air through this gap, where it is preheated before entering the combustion chamber through the holes to support combustion.

A rechargeable battery drives the fan, and most stove models include a regulator to adjust fan speed, thereby controlling heat output. An increasing number of stoves now offer Bluetooth, Wi-Fi, or mobile network connectivity, enabling Internet of Things (IoT) functionalities, such as operational monitoring and Pay-as-you-go capabilities. This supports innovative financing models and allows for highly accurate carbon accounting for carbon credit programmes. A success story in this context has been the dissemination of Ecosafi stoves, a project that achieved a high level of reliability in terms of carbon savings and, due to its high quality, also commanded much higher carbon credit prices than other projects (https://bezerocarbon.com/case-studies/ecosafi).

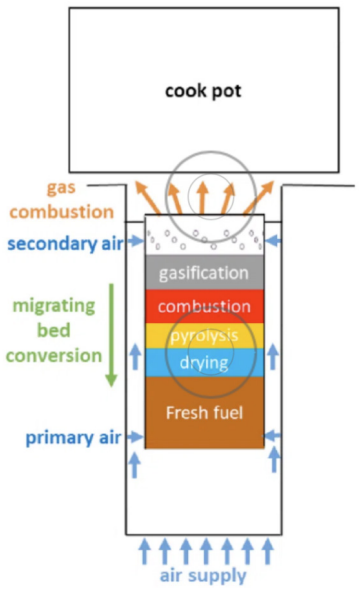


Figure 13: Schematic of a forced-draft gasifier cookstove showing combustion zones and airflow (Scharler et al., 2021).



Figure 14: Top view of the Ecosafi forced-draft gasifier cookstove.

Currently, most gasifying cookstoves on the market are designed for use with pelletized fuel. The high energy density of pellets allows the design of fairly small combustion chambers while still achieving sufficiently long combustion times of approximately one hour, and in some cases even two hours. Most gasifying cookstoves allow only batch operation—the addition of fuel during stove operation is not possible. Burning time can be controlled by adding more or less fuel at the beginning of the process or by selecting smaller or larger combustion chambers for the specific cooking task.

Chips or crushed biomass have a significantly lower energy density, so larger combustion chambers are needed to hold enough fuel to burn for a sufficiently long time. New stove models also allow fuel to be added during operation.

3.3.2 ECOSAFI "BETTERSTOVE" PELLET COOKSTOVE

The "BetterStove" is among the most advanced designs available. It has market-leading thermal efficiency and delivers LPG-like performance, with fuel that costs only about half the price of charcoal. The stove is also equipped with an IoT device that allows precise monitoring of stove use to generate high-quality carbon credits and to monitor possible technical issues. The stove is produced in China and is currently marketed in Kenya and Uganda, with expansion plans to a number of other countries.



Figure 15: Household using the EcoSafi "BetterStove" pellet cookstove.

3.3.3 FAB STOVE

The Fab biomass gasifier stove has been designed to burn biomass pellets in urban and peri-urban environments. Its primary purpose is to provide advanced clean cooking services to households using renewable solid biomass fuels, produced locally from available waste resources.

The Fab stove has been tested at an internationally recognized laboratory and meets full ISO Tier 4 standards for energy efficiency, low emissions, and safety. It has been developed by Ekasi Energy and is currently produced by Ener-G-Africa.

3.3.3.1 Modular Design

- The Fab is constructed using a modular frame design, comprising a cooktop, fan base and four legs.
- The removable fire chamber consists of a gasifier frame and a replaceable fire chamber, available in two sizes (80 mm and 95 mm).
- The fan base contains a serviceable fan kit, including a coaxial DC fan and a fan speed controller to regulate burn intensity.
- The fan is powered via a USB cable and external power source.
- All components are replaceable, with spares readily available.

3.3.3.2 Local Assembly

- Parts are shipped in flat packs to country operations, reducing shipping costs.
- Local assembly workshops construct the stoves, providing employment and lowering production costs.
- The tooling cost for a local assembly workshop is approximately $8,000.



Figure 16: A woman using the Fab biomass gasifier stove.

3.3.4 SSM PELLET COOKSTOVE

SSM, a company based in China, has developed clean-burning cookstoves for wood fuels for over 30 years. Its latest model, the F28 pellet cooker, delivers high efficiency (up to 63 per cent when used with a “super pot” featuring an integrated pot skirt). The stove offers good controllability of power output, ranging from 2,000 W and 3,000 W, with a burning time of up to 90 minutes, depending on the type of pellets used.

The F28 is marketed in Rwanda, Kenya, Tanzania, Guinea, Burkina Faso, Congo, Angola, as well as in a number of Asian, European, and American countries.



Figure 17: The SSM F28 pellet cookstove in use.

3.3.5 SUPAMOTO

The SupaMoto stove is a robust, Tier-4 micro-gasifier engineered for high-volume production and long-term durability. It combines fuel efficiency, high performance, user safety, and cost-effectiveness. Manufactured in Southern Africa, it benefits from SADC customs zero-rating, enabling efficient regional scale-up.

As one of the world's first IoT-enabled stoves, SupaMoto supports real-time monitoring and integration with digital Measurement, Reporting, and Verification (dMRV) systems, making it suitable for premium carbon credit programmes. Drawing on over a decade of experience, SupaMoto has refined its design into a dependable, data-driven, and transformative clean-cooking solution for mass markets.



Figure 18: Woman holding the SupaMoto stove.

3.3.6 MIMI MOTO AND IRYACU PELLET COOKSTOVE

The Mimi Moto cookstove is the first pellet-fired cookstove to achieve Tier 4 performance. Designed in the Netherlands and produced in China, its distinctive feature is an interchangeable burning chamber available in three sizes to suit different cooking purposes and required firepower. The stove provides adjustable firepower between 1.2 kW and 5 kW, with a cooking time of up to 90 minutes.

Mimi Moto's electric and combustion components have been used in the recently launched Iryacu cookstove, developed by BioMassters in Rwanda. The Iryacu stove uses locally sourced materials such as bricks and cement for its outer body. This makes it an affordable, durable pellet cookstove that supports local economies.

Mimi Moto products are marketed in over 20 countries, including Kenya, Rwanda, Zambia, Malawi, Tanzania, Ghana, Uganda, South Africa, Mozambique, and Indonesia.



Figure 19: Mimi Moto and Iryacu stoves: high-efficiency, durable, and locally adapted pellet cookstoves (www.mimi-moto.com; https://biomassters.co/iryacu/).

3.3.7 THE GASIO STOVE

The GaSIO cookstove, developed by the Vietnamese company CCS, represents a transformative solution for clean cooking. It uses complete biomass gasification with continuous operation, delivering thermal outputs ranging from 0.9 kW to 18 kW. Unlike most other cookstoves using the gasification principle, the GaSIO does not rely on batch feeding and can be continuously fed with fuel, providing unprecedented controllability of output power.

Its high thermal output of up to 18 kW enables use not only in households but also in commercial and institutional contexts, such as restaurants and school kitchens. The stove can also be used with dry wood chips and does not rely on pellets.

The GaSIO stove achieved a Tier 5 rating in all metrics—thermal efficiency, CO emissions, safety, and durability—except for PM2.5, which achieved Tier 4, based on testing at CREEC, Uganda under ISO 19867-1:2018 standards.

When operated with wood chips, the stove produces high-quality biochar, offering an additional benefit to users who usually prefer stove stacking and could produce their own charcoal in this way. The biochar can be used either directly for other cooking tasks or extinguished and sold.



Figure 20: A clean, high-intensity flame produced by the GaSIO continuous-feed biomass gasification stove.

3.4 Clean Institutional Cooking

Institutional cooking, particularly in school kitchens, plays a crucial role in child nutrition. Given the young demographics of many African societies, more than a third of the population is still enrolled in school, highlighting the importance of school meal programmes.

Recently, the World Bioenergy Association (WBA) initiated a pilot project in Rwanda together with the local pellet producer BioMassters. European pellet burners were used to retrofit existing school cookstoves that previously relied on firewood. The results have been excellent: fuel demand was reduced to half or even one third of the previous firewood demand, working conditions for cooks improved significantly, food quality was enhanced, and operational costs decreased (Roelofs, 2025). Similar pilot projects are currently underway in Uganda and Kenya. Preparations are being made in Rwanda to convert 100 school kitchens to pellet cooking by 2026.



Figure 21: School cookstove retrofitted with pellet burner.

A dedicated institutional pellet cookstove, offering top-level efficiency, has been developed through a joint project by WBA and a leading European pellet heating company. The first units of this stove will be produced by the Kenyan company Ecobora.

3.5 Examples of Successful Business Models

3.5.1 BIOMASSTERS

BioMassters provides advanced clean cookstoves designed to replace charcoal and firewood in Rwanda. Its portfolio includes the Iryacu stove, a locally designed and produced brick/mobile model that combines modern efficiency with traditional cooking methods, and the InzuChef stove, an imported mobile model from China that is lightweight and portable, ideal for more transient households. All BioMassters stoves use Tier 4 pellet gasifier technology, ensuring high efficiency, low emissions, and fast cooking times.

The Iryacu stove is assembled in Kigali, creating local employment while offering a product that is durable, affordable, and scalable. BioMassters combines stove supply with a secure pellet fuel system to enable customers to make a complete switch to clean cooking. Pellets are manufactured at the company's factory in Rwanda from sustainably sourced local residues from wood processing and are distributed through BioMassters' retail shops, franchises, and direct institutional deliveries. Logistics partners use electric trucks to restock retail outlets, reinforcing a low-carbon supply chain.

Through Memoranda of Understanding with the Rwanda Housing Authority and the Ministry of Education, BioMassters is scaling clean cooking in affordable housing and schools. Households in government-subsidized housing receive built-in pellet stoves, while schools are retrofitted with pellet burners and provided with regular fuel deliveries to replace firewood. By pairing stove adoption with guaranteed pellet access, BioMassters addresses the critical challenge of reliability in clean cooking markets.

3.5.2 ECOSAFI

EcoSafi provides a clean cooking solution that removes barriers to adoption, and offers families savings from the very first meal they cook. Families are provided a best-in-class fan gasifying stove for a nominal deposit, in exchange for agreeing to purchase pellet fuel produced from agricultural waste.

This solution is 98 per cent cleaner than cooking with charcoal, uses no trees, and costs approximately half as much as charcoal for the same cooking tasks. Families can cook what they want, how they want, without the need for special pots or pans. The stove is simple and easy-to-use, and offers a wide range of temperature control via a dial.

Individual customer baseline surveys, along with fuel purchase and stove use data, are used to calculate carbon emission reductions. EcoSafi is proud to be the first and only “AA” rated carbon cookstove project in the world, placing it in the top 2 per cent of all climate solutions worldwide for provable impact.

3.5.3 EKASI ENERGY: THE FAB STOVE AS A PROJECT ENABLER

Sustainable clean fuel production is at the core of any clean cooking project offering modern cooking solutions. The Fab stove is designed to complement localized pellet fuel production in diverse markets in several ways:

- Local assembly of stoves from kits.
- Smart fan kits that can be deployed in carbon reduction projects as Stove Usage Monitors (SUMs) or as PAYGO devices where credit options are offered.

This approach enables fuel production companies to enter domestic markets without significant upfront investment in stove technology, while leveraging stove funding mechanisms to support market growth.



3.6 Overview of Current Pellet Market Development in Sub-Saharan Africa

At present, a significantly growing number of pellet production projects are under way in SSA. The projects reported in this document reflect those currently known, though the list is not exhaustive and will require updating over time. Overall, these projects have an annual production capacity of more than 500,000 t, sufficient to supply cooking fuel for more than 5 million people. However, actual production at most plants is considerably lower than their installed capacity. Pellet consumption per household (five persons) is reported at around 0.5 kg (Bailies, 2020), (Zulu *et al.*, 2024), and pellets are often used alongside other fuels rather than as the sole source of energy. Without stove stacking, 1 kg of pellets would likely be sufficient to cover most cooking needs.

The key challenge in developing pellet cooking infrastructure in SSA is the need to both build a market for pellet cookstoves and ensure a reliable fuel supply. In other words, significant investment in pellet plants is required despite the absence of established market demand. In order to overcome this dilemma, companies have developed complex business models that include both cookstove sales and pellet production.

Consequently, projects are struggling with difficult economic conditions and serious funding constraints. Underinvestment in pellet plants frequently results in lower-than-expected production and issues with supplying growing demand. Additionally, limited technical experience with pellet production creates further challenges for many start-ups.

The emerging African pellet sector would most benefit from experienced pellet producers with access to sufficient capital to invest in industrial-standard production equipment and marketing to rapidly build market demand.

Other factors that have slowed sector development in the past include:

- **Limited industrial processing facilities:** Few large sawmills or agricultural processing plants exist to provide residual biomass that can be used for pellet production. An exception to this are sugar mills, some of which produce large amounts of bagasse that is often landfilled due to the absence of cogeneration units. This material could easily be used as raw material for pellets.

- **Transport logistics:** Poor logistics present both a challenge for procuring raw materials for pellet production and for distributing the fuel. Current efforts to disseminate pellet cooking are focussed on urban areas, where people are used to purchase fuel, partly also for logistic reasons. High transport costs are also hindering pellet imports, which could serve as an interim solution for building up markets until local production is viable.
- **Electricity supply:** Poor electricity supply is another challenge that in some cases keeps pellet production from operating in a consistent way. For example, some plants report an average of only seven hours of electricity per day, and sudden outages can damage pelleting equipment. Backup electricity is needed but often unavailable due to limited resources.

Despite these challenges, there are important opportunities:

- **Large market potential:** In 2018, SSA produced 32 million tonnes of charcoal for cooking (FAO, 2020), mainly in urban settlements. While charcoal has about twice the energy content per kg as pellets, traditional charcoal stoves are only about half as efficient as gasifying pellet cookstoves. As a result, 1 kg of pellets can replace about the same amount of charcoal, making pellets a cheaper choice than charcoal—and even more so compared to LPG or electricity, which are two to three times more expensive per unit of delivered energy.
- **Pellet imports:** Importing pellets could be a way of reducing the risk of investing into a pelleting plant before a substantial market has been established. Interestingly, there is no evidence of imports playing a relevant role for African pellet cooking projects. To some extent, this may be justified by the high transport costs—particularly to areas far from sea ports. On the other hand, large volumes of pellets are being traded internationally, and it should be easy to import some of these volumes from reasonably nearby producers (e.g., South Africa, Cameroon, Brazil, Viet Nam) at costs likely lower than local productions. Somehow this opportunity seems overlooked or has been rejected due to the commitment to support local economies (while other fuels, such as LPG, that are exclusively imported seem to raise less concern about these aspects).
- **Biomass from invasive species:** Many African countries have invasive species that pose significant environmental threats, which could be used as low-cost feedstock for pellets or chips.
- **Abandoned or overgrown plantations:** Overgrown eucalyptus or other plantations provide abundant sources of biomass in some areas.
- **Dedicated biomass production:** Fast-growing grasses (e.g., Miscanthus, Napier grass, bamboo, or energy cane) and short-rotation tree plantations can provide a sustainable supply of raw material. Some producers have already begun pursuing this route.

3.7 Pellet Production Plants in Sub-Saharan Africa

The annual production capacity reported in this table is based on the assumption that each pellet mill operates at nominal capacity for 5,000 hours per year. Actual pellet production may differ considerably from this capacity due to factors such as single-shift operation, lack of market demand, limited raw material supply, intermittent electricity supply, and other operational constraints.

Table 4: Pellet Sector Development Status in Sub-Saharan Africa.

Country	Location	Operator	Raw material	Annual capacity (t)	Status
Burundi	Bujumbura	KTF Concept	Rice husk, wood residues and coffee husks	1.800	producing
Cameroon	Douala	La Compagnie Générale des Granulés	wood residues	50.000	producing
Ethiopia	Addis Abeba	Anega Energies	spent coffee grounds, woodchips, sawdust, coffee husks	2.500	producing
Kenia	Owendo	Ecosafi	Bagasse	5.000	producing
Kenia	Enoosaen	Ecosafi	Bagasse	10.000	in development
Malawi	Muzuzu	Emerging cooking Solutions	Forest plantation waste	50.000	in development
Madagascar	Fort Dauphin	Madavance, Sanitap	Sawmill residues	5.000	in development
Rwanda	Gisenyi	Biomassters	Sawmill residues	10.000	producing
Rwanda	Gasabo	Ecogreen Solutions ltd.	Sawmill residues	10.000	producing
Rwanda	Bugarama	Bioenergy Company	Rice husks	5.000	producing
Rwanda	Gatsibo	Bioenergy Company	Rice husks	10.000	planned
Sambia	Ndola	Emerging cooking Solutions	Sawmill residues	10.000	producing
Sambia	Lusaka	Emerging cooking Solutions	Forest Plantation waste	100.000	in development
Sambia	Katende	Big Grass Investments	Crop residues, wild Miscanthus	5.000	in development
Uganda	Kampala	Tru Biomass	Agro residues (Groundnut shells, coffe husks)	1.000	producing
Uganda	Mukono	Global Paper	Wood residues	10.000	producing
Uganda	Namanve	Bioburn Energy Solutions	Agro residues	13.000	producing
Uganda	Kiryandongo	Kingdom rice	Rice husks	16.000	producing
Uganda	Apac	CEPA Ltd.	Agro residues	10.000	producing
Senegal	Sakar	Jord	C4 Grasses	50.000	planned
South Africa	Port Elisabeth	Coega Biomass	wood from invasive species	120.000	producing
South Africa	Pietermaritzburg	HVE Woodpelleting	pine residues (FSC)	18.000	producing
South Africa	Cape Town	CSE Biomass	pine residues (FSC)	6.000	producing

3.8 Recommendations to Advance Clean Solid Biomass Cooking

3.8.1 DEVELOPMENT OF RELIABLE SUPPLY CHAINS FOR PELLETS AND CHIPS

The availability of upgraded solid biomass fuels is an essential precondition for the successful dissemination of clean solid biomass cooking. In terms of setting up production facilities for pellets, several key issues need to be addressed:

- **Awareness of investment opportunities:** Upgrading solid biomass offers a real economic opportunity that should be clearly understood by enterprises with the potential to invest.
- **Pilot projects demonstrating good practice:** Early investments in pellet production plants or chip supply chains should demonstrate good practices. Successful pilot projects help build confidence and encourage further development, while poorly performing projects are unlikely to stimulate additional investment.
- **Access to capital on reasonable terms:** High capital costs are a key issue hindering development and often leading to underinvestment and poorly performing plants. A financial institution offering a dedicated line of financing, that understands the economics and technology of pelleting plants and that connects investors with qualified advisors, would play a key role for supply chain development.
- **Chips as a low-investment entry point:** Producing biomass chips offers a low-cost pathway for operators in the existing charcoal supply chain to transition to cleaner technologies. Chips consume less biomass while still providing high-quality fuel. Demonstration projects are needed to illustrate these opportunities and kick-start development.

3.8.2 ASSESSMENTS OF AVAILABLE RAW MATERIALS

Investment in pellet production facilities would be easier if reliable information on potentially available raw material was available. National or regional surveys carried out by universities could provide the needed data at low cost and help incentivise investment in suitable regions.

Similarly, trials with potential purpose-grown crops for the provision of raw material would provide valuable data for developing projects. Fast-growing plants such as various grasses, energy cane, bamboo, or fast-growing trees offer great opportunities to create sustainable local bioenergy businesses while generating additional income for farmers.

3.8.3 AWARENESS CAMPAIGNS

Public education on the health, economic, and convenience benefits of pellet cooking compared to charcoal and firewood is essential to stimulate demand. Due to the small scale of economic operators currently active in this sector, funding for awareness campaigns is hardly available.

Policymakers have unique opportunities to engage the media and raise public interest in priority topics. They can also set an example by converting kitchens in public institutions to pellet cooking, widely communicating these efforts, and raising interest and confidence in the new fuel.

3.8.4 RAMPING UP DEMAND BY INDUSTRIAL USERS

Pellet and chip producers need to establish demand quickly to be able to operate efficiently. Commercial and industrial users can play a key role in this context, as they often rely on highly inefficient energy supply based on firewood or charcoal. They can benefit greatly from a transition to modern technologies using upgraded fuels, but need to be made aware of the opportunities and the corresponding technologies.

3.8.5 CREATING DEMAND IN INSTITUTIONAL COOKING

School kitchens are among the largest users of firewood in SSA and can benefit hugely from advanced technologies using pellets or chips as fuel. The same applies to a diversity of other large kitchens supplying hospitals, prisons, barracks, and other institutions. These users offer policymakers an opportunity to stimulate supply chain development by establishing a reliable demand through targeted conversion programmes.

3.8.6 AFTER-SALES SERVICES FOR PELLET USING EQUIPMENT

Technologies using pellets or chips as fuel are subject to high temperatures, and usually include electric and mechanical components that require maintenance and repair services. Availability of these services is essential for the establishment of a functioning market. Neglecting after-sales support can result in failed investments and disappointed customers.

3.8.7 ESTABLISH SUITABLE AND WIDELY-ACCEPTED STANDARDS FOR PELLETS

Adequate quality standards for pellets are necessary to reflect both the properties of available raw materials and the requirements of pellet cookstoves and commercial fuel users. Research is needed to develop such standards, as existing pellet standards (EN 17225-2) were designed for different market conditions, raw materials, and utilization technologies. Capacity building in this context would need to include the establishment of laboratories for fuel quality assessment.

Standards should be shared across countries in SSA to create a reasonably uniform energy market based on upgraded biomass. A certification system could enhance consumer confidence and facilitate trade.

3.8.8 ESTABLISHMENT OF DEDICATED ASSOCIATIONS

Cooperative structures such as associations could play a key role in advocacy, communication, and market growth for pellets. They can also be instrumental in establishing pellet standards, introducing quality certification schemes, providing education and training for technical staff, and enabling peer-to-peer learning. In view of the small scale of most economic operators in the sector, funding for associations would need to rely largely on support from development finance institutions aiming to promote the growth of a sustainable local renewable energy sector.

3.8.9 FINANCIAL INCENTIVES

There are a number of financial incentives that could facilitate the market introduction of upgraded solid biomass fuels. These include: waiving VAT for pellets and chips, waiving import taxes for components of pellet cookstoves that cannot be produced locally, and providing financial incentives for investments in pellet production infrastructure.



3.8.10 VALUE GENERATION VIA CARBON MARKETS

Carbon markets offer the opportunity to raise income from stove sales, enabling a reduced price of pellet cookstoves and making investment accessible to a wider range of customers. In the past, carbon credits claimed for improved cookstoves often overstated emission reductions, leading to a loss of trust in the market. Today, IoT-enabled cookstoves allow rigorous verification of stove use and CO_2 savings.

Governments need to formally accept the corresponding adjustments to CO_2 emissions in their national greenhouse gas inventories to enable the sale of CO_2 credits generated by stove programmes.

Carbon methodologies should also take into account that mass adoption in urban settings often requires setting up market-competitive structures and value chains. Methodologies should balance documentation requirements with practicality and market realities, including franchise or third-party distributor business models that do not allow all customers to be traced back.

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Vienna International Centre -
Wagramerstr. 2, P.O. Box 300,
A-1400 Vienna, Austria

+43 1 26026-0

www.unido.org | www.cleancookingcouncil.org

ceccsecretariat@unido.org



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