# 5. Biomass Conversion Technologies

- Various technologies exist to convert biomass resources into power, heat, and fuels for use in UEMOA countries.
- Several technologies for converting bioenergy are commercial today while others are being piloted or in research and development.
- As new technologies and processes develop, the UEMOA needs to monitor progress to determine potential applications for biomass expansion.

Bioenergy consists of solid, liquid, or gaseous fuels. Liquid fuels can be used directly in the existing road, railroad, and aviation transportation network stock, as well as in engine and turbine electrical power generators. Solid and gaseous fuels can be used for the production of electrical power from purpose-designed direct or indirect turbine-equipped power plants. Chemical products can also be obtained from all organic matter produced. Additionally power and chemicals can come from the use of plant-derived industrial, commercial, or urban wastes, or agricultural or forestry residues.

Biomass resources include primary, secondary, and tertiary sources of biomass. Primary biomass resources are produced directly by photosynthesis and are taken directly from the land. They include perennial short-rotation woody crops and herbaceous crops, the seeds of oil crops, and residues resulting from the harvesting of agricultural crops and forest trees (e.g., wheat straw, corn stover, and the tops, limbs, and bark from trees). Secondary biomass resources result from the processing of primary biomass resources either physically (e.g., the production of sawdust in mills), chemically (e.g., black liquor from pulping processes), or biologically (e.g., manure production by animals). Tertiary biomass resources are post-consumer residue streams including animal fats and greases, used vegetable oils, packaging wastes, and construction and demolition debris.

There are various conversion technologies that can convert biomass resources into power, heat, and fuels for potential use in UEMOA countries. Figure 5-1 summarizes the various bioenergy conversion processes.

## 5.1 BIOMASS FOR POWER AND HEAT[6]

### 5.1.1 COMBUSTION

Biomass power technologies convert renewable biomass fuels to heat and electricity using processes similar to those employed with fossil fuels. At present, the primary approach for generating electricity from biomass is combustion direct-firing. Combustion systems for electricity and heat production are similar to most fossil-fuel fired power plants. The biomass fuel is burned in a boiler to produce high-pressure steam. This steam is introduced into a steam turbine, where

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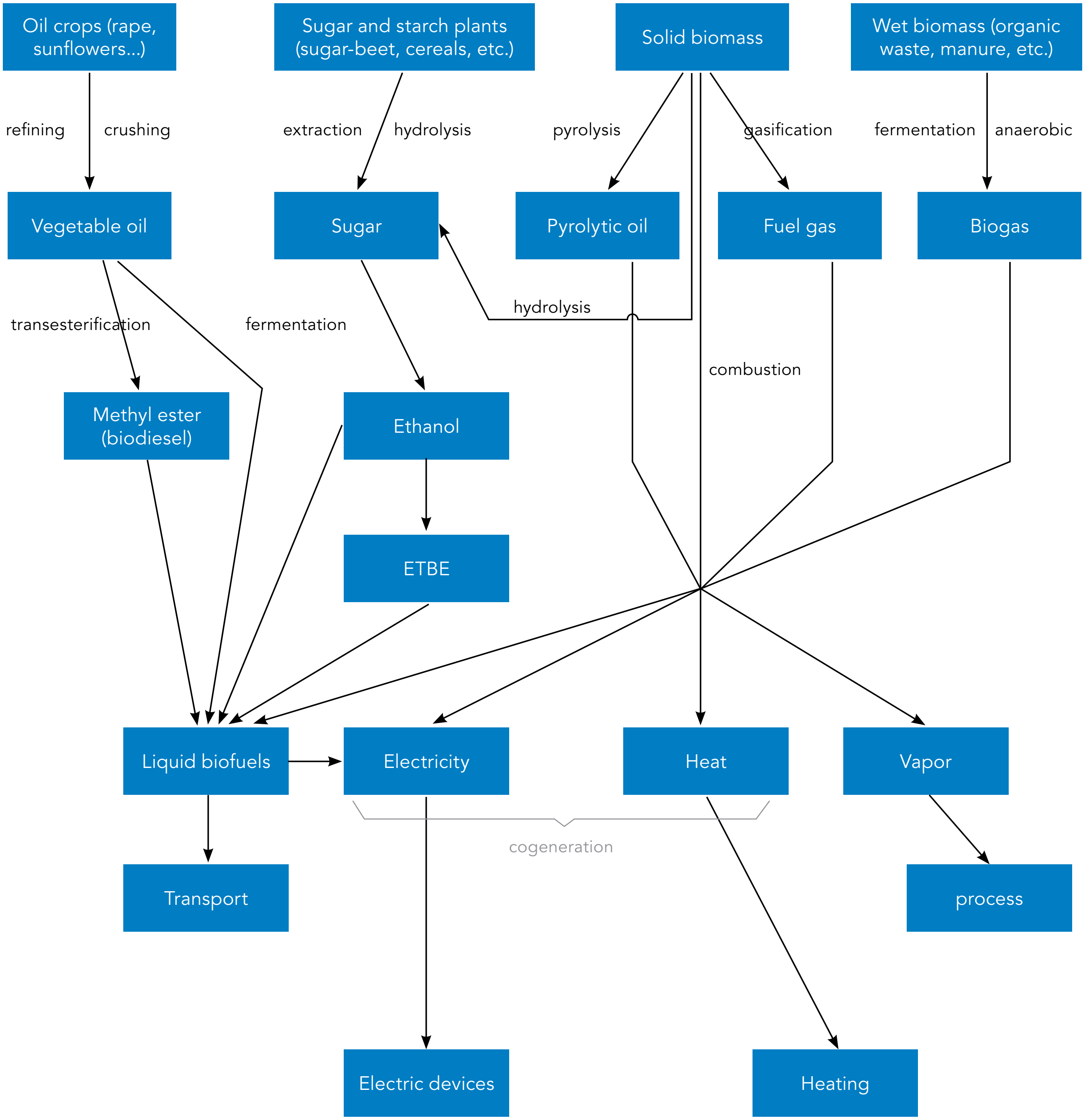
[6] ESMAP, 2005.

Figure 5-1: Biomass Energy Conversion Overview



Source: Renewable Energy World, 2006.

it flows over a series of turbine blades, causing the turbine to rotate. The turbine is connected to an electric generator. The steam flows over and turns the turbine. The electric generator rotates, producing electricity. This is a widely available, commercial technology.

Combustion boilers are available in different designs, depending on application and biomass characteristics. The main options are to burn the biomass on a grate (fixed or moving), or to fluidize the biomass with air or some other medium to provide even and complete burning. Steam turbine designs also vary in terms of their application. To maximize power production, condensing turbines are used to cool steam.

### 5.1.2 COMBINED HEAT AND POWER

Most biomass-fired steam turbine plants are located at industrial sites that have a steady supply of biomass available. These include factories that make sugar and/or ethanol from sugarcane at pulp and paper mills. At these sites, waste heat from the steam turbine can be recovered and used for meeting industrial heat needs—further enhancing the economic attractiveness of such plants. Referred to as combined heat and power (CHP) facilities (also called cogeneration facilities), these facilities are highly resource efficient and they provide increased levels of energy services per unit of biomass consumed compared to facilities that generate power only.

Conventional thermoelectric stations convert only about one-third of the fuel energy into electricity. The rest is lost as heat. The adverse effect on the environment through wasteful use of power—particularly detrimental in light of rising fuel costs—means that the efficiency of thermoelectric stations must be increased. CHP provides more efficient production of electricity, where more than four-fifths of the fuel's energy is converted into usable energy, resulting in both economic and environmental benefits. Cogeneration is the consecutive (simultaneous) production and exploitation of two energy sources, electrical (or mechanical) and thermal, from a system utilizing the same fuel. CHP could be applied to industry in West Africa where there is simultaneous demand for electricity and heat.

In UEMOA countries, there is also significant need for cooling (including refrigeration and air conditioning). Heat from a CHP plant can be used to produce cooling via absorption cycles.

At present, most biomass-fired power plants rely on low-cost (or no-cost) biomass residues. In the UEMOA, given the breadth of sugarcane processing industries, significant opportunities exist, particularly for steam-based CHP generation.

## 5.2 BIOGAS

### 5.2.1 GASIFICATION

Like coal, biomass can be a cumbersome fuel source because it is a solid. By converting biomass into a gas, it can then be made available for a broader range of energy devices. For example, biomass-sourced gas can be burned directly for heating or cooking, converted to electricity or mechanical work (via a secondary conversion device such as an internal combustion engine), or used as a synthetic gas for producing higher quality fuels or chemical products such as hydrogen or methanol.

Gasifiers operate by heating biomass in an environment where the solid biomass breaks down to form a flammable gas. The biogas can be cleaned and filtered to remove problem chemical compounds. The gas can be used in more efficient power generation systems called combined-cycles, which combine gas turbines and steam turbines to produce electricity.

### 5.2.2 ANAEROBIC DIGESTION

Anaerobic digestion is a commercially proven technology and is widely used for recycling and treating wet organic waste and waste waters. It is a type of fermentation that converts organic material into biogas, which mainly consists of methane (approximately 60%) and carbon dioxide (approximately 40%) and is comparable to landfill gas.

Similar to gas produced via gasification above, gas from anaerobic digestion can, after appropriate treatment, be burned directly for cooking or heating. It can also be used in secondary conversion devices such as an internal combustion engine for producing electricity or shaft work. Virtually any biomass except lignin (a major component of wood) can be converted to biogas—including animal and human wastes, sewage sludge, crop residues, industrial processing byproducts, and landfill material.

The conversion of animal wastes and manure to methane/biogas can yield significant health and environmental benefits. Methane is a greenhouse gas (GHG) that is 22 to 24 times more powerful than carbon dioxide ($CO_2$) in trapping heat in the atmosphere. By trapping and utilizing the methane, GHG impacts are avoided. Further, the pathogens existing in manure are eliminated by the heat generated in the biodigestion process and the resulting material provides a valuable, nutrient-rich fertilizer.

Small-scale biogas digesters have been used throughout many developing countries, most notably China and India, but also Nepal, South Korea, Brazil, and Thailand.

## 5.3 BIOFUELS

### 5.3.1 OVERVIEW[7]

Liquid biofuels include pure plant oil, biodiesel, and bioethanol. Biodiesel is based on esterification of plant oils. Ethanol is primarily derived from sugar, maize, and other starchy crops. Global production of biofuels consists primarily of ethanol, followed by biodiesel production. These are described below.

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[7] UNDESA, 2007.

- **Straight Vegetable Oil (SVO)/Pure Plant Oil (PPO):** SVP/PPO can be used in most modern diesel vehicle engines only after some technical modifications. Principally, the viscosity of the SVO/PPO must be reduced by preheating it. However, some diesel engines can run on SVO/PPO without modifications. PPO is obtained from edible oil-producing plants such as the African palm, groundnuts, cotton seeds, sunflower, canola, or non-edible oils such as jatropha, neem, or even balanites. These raw oils, unused or used, can be employed in certain diesel engines, for cooking, or in diesel generators for the production of electricity.
- **Biodiesel:** Biodiesel can be used in pure form or may be blended with petroleum diesel at any concentration for use in most modern diesel engines. Biodiesel is raw vegetable oil transformed, treated, and standardized through chemical processes. The standardization of this product, and its industrial production, renders its use much more diverse than PPO. Biodiesel is used in diesel engines and diesel vehicles. Biodiesel can be produced from different feedstocks, such as oil feedstock (e.g., rapeseed, soybean oils, jatropha, palm oil, hemp, algae, canola, flax, and mustard), animal fats, and/or waste vegetable oil.
- **Alcohols:** Ethanol, butanol, and methanol are produced principally from such energy crops as sugarcane, maize, beets, yam, or sweet sorghum. Ethanol is the most widely used alcohol, primarily as a fuel for transportation or as a fuel additive. Bioethanol can be produced from a variety of feedstocks, including sugarcane, corn, sugar beet, cassava, sweet sorghum, sunflower, potatoes, hemp, or cotton seeds, or derived from cellulose waste.

Several processes exist to convert feedstocks and raw materials into biofuels. First-generation biofuels refer to the fuels that are produced through well-known processes such as cold pressing/extraction, transesterification, hydrolysis and fermentation, and chemical synthesis. The resulting fuels have been derived from sources such as starch, sugar, animal fats, and vegetable oil. First-generation biofuels are already established in the fuel markets and usually produced from fuel crops. The most popular types of first-generation biofuels are biodiesel, vegetable oil, bioethanol, and biogas.

Second-generation biofuels are not yet commercial on a large scale as their conversion technologies are still in the research and/or development stage. Second-generation biofuels are produced through more advanced processes, including hydro treatment, advanced hydrolysis and fermentation, and gasification and synthesis. A wide range of feedstocks can be used in the production of these biofuels, including lignocellulosic sources such as short-rotation woody crops. These produce biodiesel, bioethanol, synthetic fuels, and bio-hydrogen (see Box 5-1).

Table 5-1 shows the production and use of liquid fuels for first- and second-generation biofuels.

### 5.3.2 FIRST- AND SECOND-GENERATION TECHNOLOGIES: ADVANTAGES AND DISADVANTAGES

Both first- and second-generation technologies offer advantages and disadvantages. The primary advantage of first-generation biofuels is they are available today with existing technologies; their promotion is based on non-technical issues such as policies and cost-effectiveness. First-generation biofuels can also be produced in decentralized facilities. Disadvantages include emissions produced in growing and refining these fuels, land use concerns, their complex effect on food and grain prices, and that only specific crops can be used in biofuels production.

For second-generation biofuels, a larger variety of feedstocks can be used. Advanced biofuels (e.g., biobutanol and synthetic diesel) and other biofuels derived from switchgrass, garbage, and algae are under development. New conversion technologies are expected to expand production potential by allowing for the use of an array of non-food resources. Additionally, the energy input for agriculture and feedstock production could be significantly reduced and the technologies are expected to be more efficient as they will entail large-scale conversion operations. It is anticipated that second-generation technologies will yield better energy, economic, environmental, and carbon performance than first-generation options, yet this remains to be proven (Hunt, 2008; Janssen et al., 2008).

### Box 5-1: Biodiesel and Bioethanol Production

In the first-generation production of biodiesel, oilseeds are crushed to extract oil. The residue cake, depending on its characteristics, can be used as a fertilizer, animal feed, or biomass energy feedstock. To produce the biodiesel, the raw plant oils extracted are filtered and mixed with ethanol or methanol to initiate an esterification reaction. This process separates fatty acid methyl esters, which are the basis for biodiesel; the glycerin can be used in soap manufacture. Small-scale cultivation of fuel crops for biodiesel is typically more cost-effective if the various byproducts are used economically or commercially. Direct use of plant oils for cooking or lighting is possible, but requires modified cookstoves or lamps.

Bioethanol is primarily produced by fermentation of sugarcane or sugar beet. The sugarcane or sugar beet is harvested and crushed, and soluble sugars are extracted by washing the pulverized cane with water. Alternatively, second-generation bioethanol can be produced from wood or straw using acid hydrolysis and enzyme fermentation. This developing process is currently more complex and expensive. First-generation bioethanol from a cereal such as wheat requires an initial milling and malting (hydrolysis) process. Malting occurs under controlled conditions of temperature and humidity. Enzymes present in the wheat break down starches into sugars. Production of bioethanol from maize is a similar fermentation process, but the initial processing of the corn is different. First, the corn is milled either by a wet milling or by a dry milling process. Enzymes are then used to break down the starches into sugars that are fermented and distilled. Residues from corn milling can be used or sold as animal feed.

## Table 5-1: Production and Use of Liquid Biofuels

| First Generation (Conventional) Biofuels | | | | |
|---|---|---|---|---|
| **Biofuel Type** | **Specific Names** | **Biomass Feedstock** | **Production Process** | **Uses** |
| Vegetable/Plant Oil | Straight Vegetable Oil (SVO)/<br>Pure Plant Oil (PPO) | Oil crops (e.g. Rapeseed, Corn, Sunflower, Soybean, Jatropha, Jojoba, Coconut, Cotton, Palm, etc.)<br>Algae | Cold pressing/ extraction | Diesel engines, generators, pumping (all after modifications);<br>Use for cooking and lighting, as possible;<br>Transportation |
| Biodiesel | Biodiesel from energy crops | | Cold pressing/ extraction & transesterification | Diesel engines for power generation, mechanical applications, pumping;<br>Transportation (diesel engines) |
| | Rapeseed methyl ester (RME), fatty acid methyl/ethyl ester (FAME/FAEE) | | | |
| | Biodiesel from waste FAME/FAEE | Waste/cooking/ frying oil/animal fat | Transesterification | |
| Bioethanol | Conventional bioethanol | Sugarcane<br>Sweet sorghum<br>Sugar beet<br>Cassava<br>Grains | Hydrolysis & fermentation | Internal combustion engine for motorized transport |
| Bio-ETBE | Ethyl Tertiary Butyl Ether | Bioethanol | Chemical synthesis | |
| **Second Generation Biofuels** | | | | |
| Biodiesel | Hydro-treated biodiesel | Vegetable oils and animal fat | Hydro-treatment | Internal combustion engine for motorized transport |
| Bioethanol | Cellulosic bioethanol | Lignocellulosic material | Advanced hydrolysis & fermentation | |
| Synthetic biofuels | Biomass-to-liquids (BTL):<br>Fischer-Tropsch (FT) diesel<br>Biomethanol<br>Biodimethyl-ether (Bio-DME) | Lignocellulosic material | Gasification & synthesis | |
| Bio-hydrogen | | Lignocellulosic material | Gasification & synthesis or biol. | |

Source: UNDESA, 2007.

## 5.4 BIOREFINERIES

An emerging concept for the UEMOA to be aware of is biorefineries. A biorefinery involves the co-production of a spectrum of bio-based products (food, feed, materials, chemicals) and energy (fuels, power, heat) from biomass (IEA Bioenergy Task 42).

A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and value-added chemicals from biomass. The biorefinery concept is analogous to today's petroleum refinery, which produces multiple fuels and products from petroleum.

### Box 5-2: Green Charcoal: An option to reduce deforestation

Several endeavors are underway across Africa to replace wood charcoal with environmentally friendly alternatives.

After taking part in the Tanzanian Environmental Education Programme (TEEP), funded by the conservation organization World Wide Fund for Nature (WWF), Yohana Komba used traditional knowledge and local resources to create an environmentally friendly alternative to traditional charcoal.

The green or vegetable charcoal Komba developed is made from soil, ash, and wild vegetation. The vegetation is boiled in water until a thick, elastic paste forms and then the paste is mixed with soil and ash. The mixture can then be molded into fist-sized nuggets that are dried for five days before they are ready for use. Tests on the green charcoal have shown that it burns longer than conventional charcoals, is environmentally friendly, and has no side effects for users. It has also reduced deforestation in the region.

The NGO Pro-Natura International has patented an innovative continuous process of biomass carbonization that can transform agricultural residues or renewable biomass into green charcoal pellets or briquettes that perform the same as charcoal made from wood, at half the cost. This new system will create new jobs in rural areas, and represents a release from the constraints of scarcity, distance, and cost of available fuels in Africa. The Pro-Natura pyrolysis system has been successfully piloted in Senegal and South Africa, and there are plans to introduce the system in Mali.

While similar to wood charcoal in terms of calorific properties, green charcoal presents several advantages:

- Job creation in rural areas;
- Reduced deforestation related to the production of wood charcoal;
- Avoidance of methane emissions resulting from traditional wood charcoal production techniques; and
- Abatement of $CO_2$, methane, and nitrous oxide emissions resulting from the burning of agricultural residues.

By producing several products, a biorefinery takes advantage of the various components in biomass and their intermediates, therefore maximizing the value derived from the biomass feedstock. A biorefinery could, for example, produce one or several low-volume, but high-value, chemical products and a low-value, but high-volume liquid transportation fuel such as biodiesel or bioethanol. At the same time, it can generate electricity and process heat, through CHP technology, for its own use and perhaps enough for sale of electricity to the local utility. The high-value products increase profitability, the high-volume fuel helps meet energy needs, and the power production helps to lower energy costs and reduce GHG emissions from traditional power plant facilities. Although some facilities exist that can be called biorefineries, the biorefinery concept has yet to be fully realized. Future biorefineries may play a major role in producing chemicals and materials that traditionally were produced from petroleum.

## 5.5 COOKING AND RELATED APPLICATIONS

Displacing fuelwood for cooking is a key interest of many UEMOA member states. Options are discussed below (ESMAP, 2005):

- *Biomass densification or briquetting.* This is the process of compacting loose biomass feedstocks into a uniform dense form, producing a higher quality fuel. Better and more consistent thermal and physical qualities allow for more complete combustion of briquettes, providing greater efficiency, reduced emissions, and greater control for residential and industrial applications. Briquettes offer easier transport, storage, and mechanical handling in both household and industrial settings. Briquettes can be efficiently produced using relatively simple technologies. Stalks, husks, bark, straw, shells, pits, seeds, sawdust—virtually any solid organic byproduct of agricultural or silvicultural harvesting—can be used as a feedstock. Biomass wastes with relatively low moisture content (less than 15%) are most suitable for efficient production of briquettes.

- *Ethanol gel.* Ethanol gel is a clean-burning fuel that consists of gelatinized ethanol bound in a cellulose thickening agent and water. Cookstoves specially designed for use with ethanol gel have been developed in the last few years, as have ethanol gel burners that can be retrofitted into several traditional African cooking stoves. Used in such appliances, ethanol gel is a highly controllable, easily lit cooking fuel with a heating efficiency of roughly 40%. Initial market penetration has taken place in several countries in Africa, such as Zimbabwe, Malawi, and South Africa. Experience has shown that ethanol gel can substitute for wood fuels and kerosene, stabilize household energy markets, and reduce $CO_2$ emissions and indoor air pollution (see Box 5-3).

- *Improved cookstoves.* The key use for fuelwood, charcoal, and other forms of biomass in the UEMOA is for cooking. Utilizing smokeless, efficient, and low-cost stoves that exist in the marketplace today can help reduce wood fuel demand, improve indoor air pollution, and lessen deforestation.

### Box 5-3: Using Ethanol Gel to Combat Indoor Air Pollution

While interest in alternative energy and green politics is often seen as the preserve of the upper classes, working-class people in Johannesburg's inner city are already using renewable energy in their homes. On a pavement in Joubert Park in Johannesburg, shoppers cluster around Tumelo Ramolefi's stall exclaiming and asking questions about his products. Ramolefi is not selling the usual inner-city hawker stock of facecloths and socks. Instead, it is his display of innovative renewable-energy gadgets that attracts the attention of passers-by.

His bestselling items are ethanol gel stoves and lamps, which offer a healthier, safer, and more efficient alternative to paraffin or coal fires. Ethanol gel is a renewable form of energy made by mixing ethanol with a thickening agent and water. The ethanol is extracted through the fermentation and distillation of sugars from sources such as molasses, sugar cane, and sweet sorghum, or starch crops like maize. Ramolefi sells ethanol gel products and appliances for GreenHeat South Africa, with branches in Durban, Johannesburg, and Cape Town. The stoves and ethanol gel—produced from sugarcane—are manufactured in Durban. A two-plate stove sells for R160 (US$23); a lamp for R50 (US$7).

"This stove is number one," said Maria Ndlela, who works in a recycling centre in Joubert Park and has owned her stove for two months. She says it is easy to use and, while paraffin is cheaper than the gel, the gel is more cost-efficient in the long run. Five liters of gel cost R60 (US$8.50) and paraffin costs R21.99 (US$3.13) for the same amount. "Gel lasts. If you don't use it too much, five liters of gel takes you a month to use, but five liters of paraffin lasts only three days." Ndlela says an added attraction of ethanol is that the paraffin price fluctuates. "The price of paraffin is going up and down with the petrol price," she said. "So now I'm forgetting about paraffin."

"What I like about the stove is that it will conquer our unreliable electricity," said Florah Thulare. She says pre-paid electricity cards are often unreliable and problems with them can take a day or two to be resolved, leaving her without electricity to cook with at night. Safety is also a big selling point. Paraffin stoves, which explode or are easily knocked over, cause fires, and poor ventilation can lead to asphyxiation. "Coal can kill you during the night," says Ramolefi.

Gel fuel burns with a carbon-free flame, so it does not cause respiratory problems like asthma, which can be caused by emissions from paraffin, coal, and wood fuel. The gel also does not produce any smoke or smell. Gel fuel will not ignite if spilled like gas or paraffin, and it is non-toxic and thus not poisonous if swallowed by children. The stoves are designed so they will not fall over if bumped and the stove's legs allow it to slide when pushed instead of toppling over.

Ramolefi says that, even if an ethanol lamp is overturned, the gel will extinguish the wick—and if a stove is knocked over and a fire starts, it will not spread rapidly because the gel moves slowly. The stoves are designed for cooking, but half of his customers buy them as heaters. While talking to Ramolefi, Monty Marees stopped to buy a stove for her "auntie" who had just moved to the area. Marees said the elderly woman took hours each evening to collect wood and warm her mbaula, a brazier-type heater. She was buying the stove to warm her aunt before bed.

Ramolefi has sold about 70 stoves in the past eight months and hopes the market will grow and prices will drop, making the stoves more affordable for the poor. While sales were slow initially, word-of-mouth and seeing neighbors cooking on ethanol stoves has increased customers. "You can't buy something you haven't seen working anywhere. We need to demystify them for people."

Source: UNDESA, 2007.

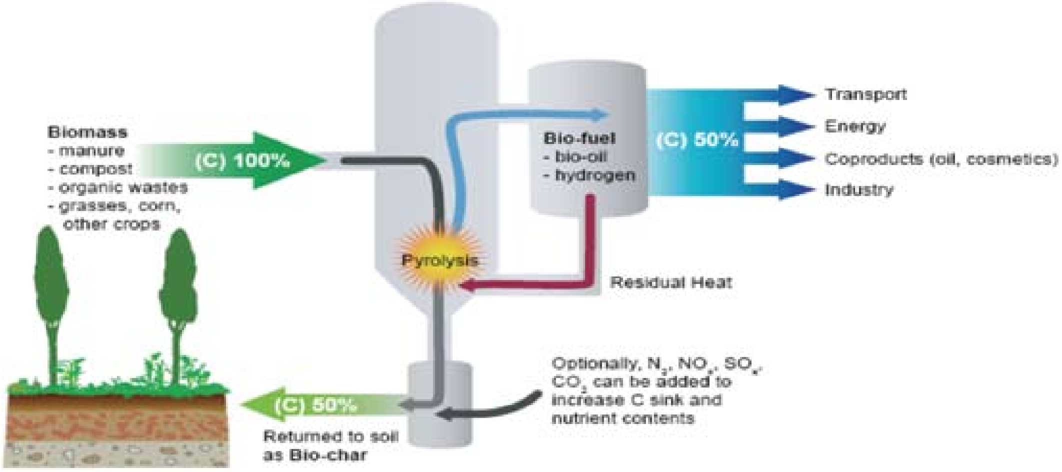
- *Improved charcoal kilns.* More efficient kilns in charcoal production are a priority for UEMOA countries as a means of minimizing wood use.

For the above options, markets may be constrained by cost factors. However, policies and incentives to reduce deforestation; eliminate subsidies for fossil fuels, such as butane; and promote alternatives to fuelwood can help address the cost constraint. Also, it is important to note that these activities should be linked to improved forest management programs and practices.

## 5.6 BIOCHAR

Any bioenergy production will lead to a removal of biomass from the land. This potentially leads to soil degradation, with negative effects on soil productivity, habitats, and off-site pollution. Pyrolysis (explained below), coupled with organic matter returned through biochar, addresses this dilemma, as about half of the original carbon can be returned to the soil. Figure 5-2 graphically depicts the biochar process.

Figure 5-2: Production of Biochar



Source: Lehmann, 2007.

Biochar is a fine-grained charcoal high in organic carbon and largely resistant to decomposition. Biochar is produced by heating biomass in the absence (or under reduction) of air, or pyrolysis. It is found in soils around the world as a result of vegetation fires and historic soil management practices. Intensive studies of biochar-rich dark earths in the Amazon (Terra Preta), have led to a wider appreciation of biochar's unique properties as a soil conditioner.

In developing countries, biochar systems can reverse soil degradation and create sustainable food and fuel production in areas with severely depleted soils, scarce organic resources, and inadequate water and chemical fertilizer supplies. Low-cost, small-scale biochar production units can produce biochar to build garden, agricultural, and forest productivity, and bioenergy for eating, cooking, drying and grinding grain and producing electricity and thermal energy (International Biochar Initiative, 2008).

Given the serious land degradation facing many of the UEMOA member states, biochar could be an option to consider.

## 5.7 SUMMARY

- A variety of technology options exist for biomass that rely on several feedstock alternatives. These options can serve many different energy needs, from large-scale industrial applications to small-scale, rural end-uses.
- A number of technologies are mature and fully commercial. These include industrial-scale biogas production and steam turbine CHP systems. Today, CHP systems satisfy electricity demand in several agro-industries (e.g., sugar, pulp, and paper industries) and provide excess power to the grid. Tremendous opportunities exist for further expanding this potential in the UEMOA.
- Other technologies are demonstrated and disseminated, but are not broadly in use in the UEMOA. Ethanol biodiesel for transport, household biogas digesters, improved cookstoves, and biomass gasifiers for thermal applications in agro-industries are technologies that have not yet broadly penetrated in the UEMOA. In other countries/regions, they have benefited from publicly supported dissemination programs and have required varying levels of public sector financial input.
- As new technologies and processes continue to develop, including second-generation options, they should be tracked and assessed by UEMOA countries for future potential application.