Renewable Energy in Kenya

MARK HANKINS

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Foreword

There is no doubt that the greatest threat to Africa's environment is the removal of the tree cover. Today, agricultural clearing, charcoal production and fuelwood collecting are removing trees from Kenya's landscape at an alarming rate. Woodfuel shortages are already realities in many parts of the country. Meanwhile, unstable prices of fossil fuels frustrate budget planners who must allocate badly needed foreign exchange to purchase petroleum. Especially affected by this energy crisis are the rural people who make daily trips in search of fuelwood and the urban poor who line up in queues to buy parafin.

However, Kenyans are beginning to use practical methods which prevent wood shortages as well as alternatives to fossil fuels. Food production and tree planting tasks are integrated to produce higher agricultural crop yields and such tree products as fertiliser, fodder, firewood and building poles. Various energy requirements are also being met by plentiful local renewable resources such as sunshine, wind, agricultural wastes and hydropower.

This book began as an attempt by the Kenya Renewable Energy Development Project (KREDP, a USAID-funded project assisted by Energy/Development International under a technical service contract in the Ministry of Energy and Regional Development) to describe and catalogue renewable energy systems now being used in Kenya.

The project was later reviewed, broadened in scope, and extended with financial assistance from the Canadian High Commission to include a greater number of projects, more details on the technologies and basic information on how to start projects.

Motif Creative Arts joined these efforts and undertook major responsibilty to design, illustrate and publish the book. Working closely with the author, Mr. Hankins, Motif Creative Arts was able to incorporate substantial improvements to make the book suitable and useful both in the classroom and outside.

The book presents realistic renewable energy choices now available to farmers, schools and small business in rural Kenya. It also serves as a valuable information resource for government, NGO and public sector agencies concerned with energy. Through eight chapters, the books first presents basic principles and useful applications of each renewable energy system. It then guides readers to local projects which, as concrete examples, will help them evaluate the utility of each renewable energy to their individual needs and resources.

For the first time, *Renewable Energy in Kenya* presents the full range of appropriate energy technologies in a readable form for local secondary and polytechnic students. As renewable energy is now part of the 8-4-4 syllabus, this book is a timely reference for teachers and students in the subject area. By expanding the awareness of renewable energies the book will increase the adoption rate and use of these technologies. In so doing, it will be a positve contribution towards solving the energy and environmental crises in Kenya.

The publication of this book is the culmination of a tremendous personal effort by the author, Mr. Mark Hankins, for which he should be highly commended. It is my hope that he will be given the opportunity to update and expand the contents of the book periodically in order to sustain its future usefulness.

Professor Amare Getahun

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This book is dedicated to the students and staff of Karamugi Harambee Secondary School whose continued interest in renewable energies were the inspiration for these chapters.

Energy and Development 1

Traditional Sources of Energy

All traditional rural societies originally depended on locally available renewable energy sources. Energy was gathered or harvested nearby; none was imported. Traditional societies made use of solar energy, wood and charcoal, plant and animal wastes, and human and domestic animal power for all of their energy needs.

Most energy was (and still is) spent in the preparation of food. Cooking tasks used wood, charcoal or plant wastes. Agricultural, pastoral, and fishing and hunting activities made use of human or animal power. Crops were dried using solar energy and then cleaned, processed and ground by human muscle in the home.

People travelled on foot, by boat or by animal power. Goods and water were transported on foot or using animals. Communication relied on messengers who travelled on foot.

Table 1.1 shows how traditionally, in the absence of large transport and industrial energy requirements, all energy supplies were renewable and locally available.

Table 1.1: Traditional Sources of Energy

USE	METHOD	ENERGY SOURCE
Cooking, space heating heating water	Open fires	Wood, charcoal plant wastes (biomass energy)
Lighting	Special types of wood and resins	Wood
Agricultural and pastoral activities	Planting, harvesting	Human and animal power (Animate energy)
Food preservation	Smoking Drying, crops and fish Grinding	Wood Solar power Human power
Small industries	House building, Smelting iron Craftswork	Animate energy Wood Animate energy
Brick & pottery making	Kilns	Wood Solar
Transportation Communication	By foot By camel, donkey By boat By dhow	Animate energy Animate energy Animate energy Wind power

Meeting Modern Energy Needs

As Kenya developed, the energy needs of Kenyans changed. Although wood still serves most of the country's energy requirements, there are important differences between today's energy consumption patterns and traditional energy needs.

Modern living styles require more energy. Transport services, industries, hospitals, and schools consume much energy while providing goods and services that improve our lives. Today, urban areas must "import" much energy from other parts of the country or from outside the country. In fact, simply keeping up with the energy requirements of the rising population makes considerable demands on the environment and economy.

The National Energy Consumption

In 1980, a study of energy use in Kenya was undertaken by the Ministry of Energy and Regional Development and a division of the Swedish Academy of Sciences called the Beijer Institute. Some of their conclusions about energy use in Kenya are summarised in Tables1.2, 1.3 and 1.4.

Who Uses Energy?

1. Rural households, which make up 85% of the population, use the highest portion of Kenya's energy. This includes 72% of the country's fuelwood. Typically a family of eight uses over 20 kilogrammes of wood per day for cooking and heating water.

2. Urban households place a great demand on the nation's charcoal supply, consuming about 50%.

3. Almost all of the transportation sector's energy takes the form of petroleum products. Transportation uses about 56% of the country's annual petroleum demand.

4. Although its overall use of energy is small, the commercial/institutional sector uses a large portion of the country's grid electricity (22%).

5. Agriculture, which supplies $^1/_3$ of the country's Gross Domestic Product (GDP) and employs $^3/_4$ of the country's labour force, uses only 2% of the country's fuel. This is misleading, however, because these figures include measurable energy only (wood, charcoal, electricity, petroleum, etc.) while agricultural work includes a lot of unmeasurable energy. Agriculture uses *animate energy* (energy supplied by domestic animals and human power) which is difficult to measure. However, a study in Somalia put domestic animal and human power at 2-3% of the total energy demand, on par with electrical energy consumption. In fact, animate energy is the backbone of Kenya's agricultural production. Agricultural processing also makes use of *solar energy* which is not easily measured.

Table 1.2: Energy Use by Sector (as a Percentage of Total Energy Use)

SECTOR	% OF TOTAL	USES
Rural household	53%	Cooking, lighting, space heating
Industry	24%	Raising steam, process heat, drying
Transportation	14%	Private vehicles, buses, *matatus*, lorries
Urban households	6%	Cooking, lighting, appliances
Agriculture	2%	Tractors, agricultural machines
Commercial/ institutional	1%	Cooking, lighting
Total	100%	

Source: Beijer Institute, 1980

The figures in table 1.3 show the sources of fuel the population and industries in Kenya use for their energy requirements. Rural households use most of Kenya's fuel energy and so it follows that their main source of energy, fuelwood, is the country's most significant source of energy. Urban households contribute to this demand by their use of charcoal.

Table 1.3: Fuel Energy Demand (By Type of Fuel)

TYPE OF FUEL	% OF FUEL ENERGY DEMAND
Wood/charcoal	69%
Non-wood biomass	3%
Petroleum products	26%
Hydro, geothermal, electric	2%
	100%

Source: Beijer Institute, 1980.

Petroleum products are quite costly. Table 1.4 shows how the prices of crude oil have changed over the last 27 years. Kenya imports crude oil and produces such products as kerosene, petrol, diesel, jet fuel and liquid petroleum gas (LPG) at the Mombasa refinery. The recent fall in the price of crude oil has helped Kenya's economy by lowering the amount of foreign exchange spent to import each barrel of crude oil. However, in the next twenty years, prices of petroleum are expected to rise again to 1982 levels.

Table 1.4: Crude Oil Imports and Net Costs (1973-1985)

K£ MILLIONS

YEAR	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Oil Imports	22.3	82.1	105.0	124.0	160.9	179.8	147.3	322.4	343.7	332.6	331.7	332.4	377.3
Net Cost of Oil After Exports	1.1	36.5	46.0	54.3	77.7	110.9	70.1	150.9	180.0	183.2	197.3	190.2	268.3

Source: Ministry of Energy and Regional Development 1986

Domestic Uses of Energy

Conserving and developing new sources of energy for households will save much time and money, as most of Kenya's fuel energy is used in households. The most important household uses of energy are described below.

Cooking, Space and Water Heating

Wood and Charcoal. Today in many places, Kenya's energy crisis is the *woodfuel shortage*. In densely populated areas (i.e. Maragoli, Nyanza, Embu) most people cook with wood or agricultural wastes. Women spend much time walking long distances in search of fuelwood.

In cities, most people cook with charcoal. Wood is scarce in towns because it cannot be economically transported over large distances. Charcoal is more convenient than wood and is more suitable for urban use, but it is expensive for those with limited incomes.

This book describes improved charcoal and wood stoves which save time and money spent collecting fuels. Improved kilns and kilning methods, which help prevent shortages of charcoal by more effectively converting wood resources, are also discussed. Furthermore, methods of increasing woodfuel (and tree product) resources are outlined.

Paraffin (Kerosene), Liquid Petroleum Gas (LPG) and Electricity. Some Kenyans (mostly in towns and cities) rely on paraffin, LPG or electricity for cooking and heating. Paraffin and LPG are both imported petroleum products. Electricity is produced locally by hydroelectric plants, geothermal plants or oil-fired generators.

Use of paraffin and LPG for cooking places no strain on the environment (no trees are cut down). However, the prices of paraffin, LPG and the stoves that use them are quite high. Few people can afford paraffin or LPG gas for cooking. Also, because Kenya already spends much of its foreign exchange on petroleum products, it is expensive for the government to support cooking with paraffin or LPG.

Use of mains electricity for cooking also costs

the government considerable foreign exchange. Although electricity is produced locally by hydropower stations and geothermal power stations, their major costs consume large amounts of foriegn exchange. Large hydroelectric dams also have adverse effects on the environment. They may cover agricultural land, they may affect downstream ecosystems and they may be a breeding ground for diseases.

Using electricity for cooking is quite costly for individuals. In comparison with lights or radios, electric cookers use very high amounts of electric power. As the rates go up, many people find that cooking and heating water with electricity is prohibitively expensive.

This book describes renewable energy systems which can be used for raising thermal energy, such as waste biomass, biogas digesters and solar water heaters. These devices are *already* replacing wasteful or unnecessary uses of petroleum and electric supplies.

Energy and Water Supply

Only 6% of Kenya's population is presently served by piped water. The Ministry of Water Development is very hard pressed to meet the rest of the population's needs. While piped water development projects continue, most of Kenya's population must expend energy on a daily basis to pump, draw or carry water for their needs.

People need water for drinking, preparing food, and for hygienic purposes. A minimum amount of clean water is necessary for healthy living standards. Livestock consume large amounts of water. The more animals there are on a farm, the more water is needed. In semi-arid areas, water is often deep below the ground surface, and must be pumped up into troughs for animals to drink.

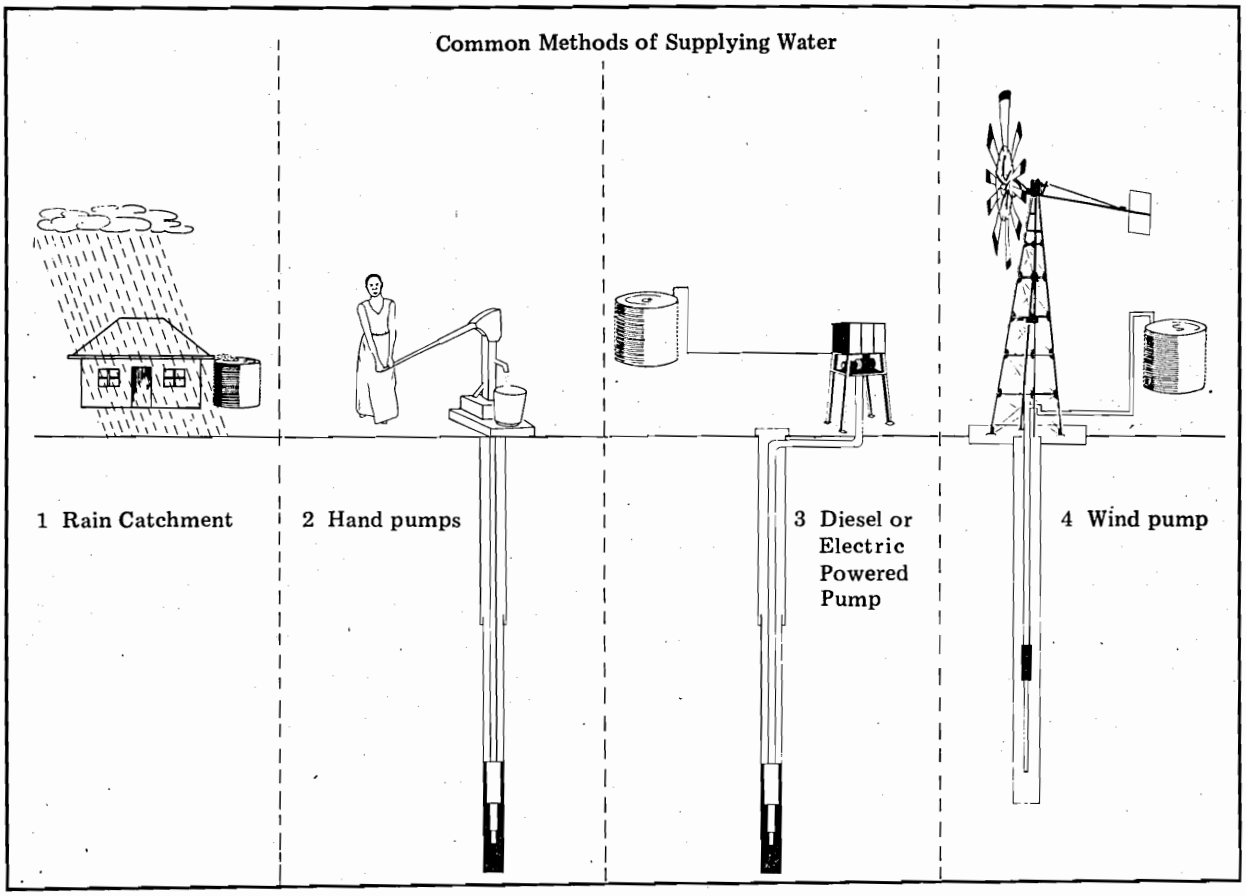
Water is also required for irrigation purposes. Small garden plots use small amounts of water to produce green vegetables during the dry season. Large-scale irrigation projects require great amounts of water in order to grow food crops at a profit.

Sources of water in Kenya vary with the climate of the area. Cities and developed rural areas often have piped water. Many institutions, schools, hospitals and small farmers collect water by rain catchment. Rain catchment with storage tanks is an excellent way for isolated communities to get clean water. Other people get their water from nearby lakes, streams, rivers or springs. Boreholes and wells are the most common sources of water in drier areas of Kenya.

Pumping and carrying water consumes time and energy. Human, animal and diesel power, as well as rain catchment, are the most common solutions to the problems of obtaining, lifting and transporting water today. This book discusses several renewable energy powered devices that help supply water for rural communities and individuals. These include windpumps, hydraulic rams, turbopumps and solar pumps.

Energy and Lighting

In rural households, over 90% of the fuel burned is used for such thermal applications as cooking, heating water and space heating. The remaining energy is mostly used for lighting. Whereas most of the daylight hours are hot and reserved for working, the



evening is cool, relaxing and a good time to study, read or engage in other productive work. Without adequate lighting, studying is not possible. Good light enables people to study, plan and do work at night.

Very few rural Kenyan homes have generators or mains power. Almost all lighting needs are met by such paraffin powered devices as hurricane lamps or simple wick lamps. Currently, paraffin is the cheapest lighting fuel. In fact, it is the only low-cost solution to the rural lighting problem presently in use. But paraffin is relatively expensive over the long term, and often in short supply.

Methods of supplying electricity for lighting, refrigeration and small appliances with renewable energies are discussed in several chapters of this book.

Energy and Agriculture

The Beijer Institute study results show that agriculture uses only 2% of Kenya's fuel energy demand. However, most of the energy input in small farms is animate energy or some other energy input which is difficult to quantify. Only very large farms can afford such agricultural machinery as tractors or threshers.

A major challenge for the Kenyan farming system is to keep food production rates up with the population growth rate. This is necessary in order to keep the country self-sufficient in food production. However, today agricultural land is severely limited, and expanding agriculture to semi-arid areas has proved to be difficult.

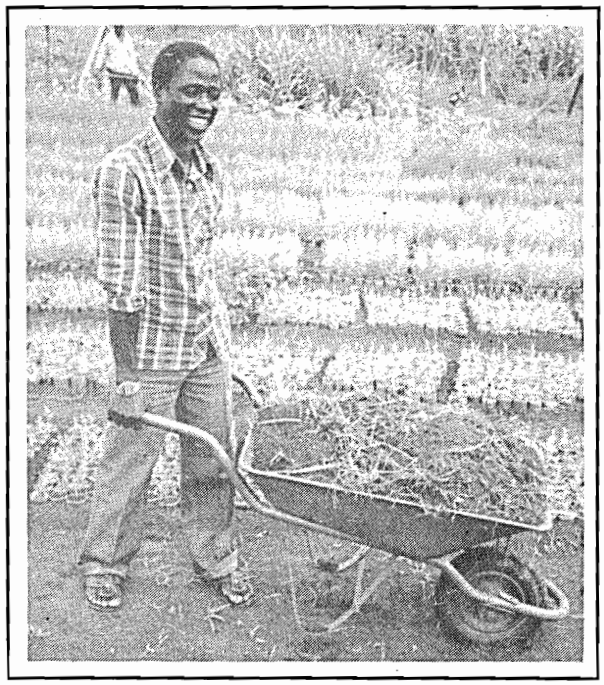
Increasing energy inputs to the land is an important way of increasing agricultural production. This involves making use of better tools, fertilisers and land management techniques.

Fertilisers

Fertiliser is a crucial input for agricultural production. Making nitrogen and other important elements available to crops consumes much energy. The commercial fertilisers commonly applied to coffee and maize fields are made from *petroleum products* using processes that consume large amounts of energy. When farmers apply commercial fertilisers to crops they are using energy-intensive crop production methods. The prices of commercial fertilisers are linked to the prices of imported petroleum products.

There are other effective ways of fertilising farmland. Animal wastes and crop residues are humus-rich fertilisers now widely used by farmers to improve the soil. They can be made even more effective as fertilisers by treating them in biogas digesters or by composting them.

Additionally, the types of *crops* planted in seasonal rotations and the types of *trees* planted on farmland have an effect on any soil's productivity. Legumes such as beans and groundnuts make nitrogen available in the soil and are thus commonly planted in between crops of maize or potatoes in *shambas* all over the country. Trees also help improve the soil. Leguminous trees, when planted in agroforestry systems (see Chap. 3), fix nitrogen and bring other nutrients below the top soil to the soil surface.



The tools a farmer uses should be fitted to the needs of the shamba *and the resources available to pay for them.*

Sources of fertilisers are thus not limited to costly commercial ones. Animal wastes and leguminous plants can both supply nitrogen to agricultural crops in a continuous solar-powered cycle.

Tools

The tools a farmer uses also have a great effect on a farm's output. Obviously a tractor can prepare much more land than a single farmer with a *jembe*. But tractors are very expensive and often unsuitable for small farms. The *tools* a farmer uses must therefore be fitted to the *needs* of the *shamba* and the budget.

Much has been done with domestic animal power to improve the output of small farms. Cattle or donkeys are used to plough fields, to harvest and to transport crops short distances. Animal power is also used to raise or pump water for irrigation and to process crops. It can thus be used to increase a farm's production by replacing human labour and expanding the amount of land under tillage. The number of animals a farm can support is limited by the amount of feedstock available, but can be increased by improved farming practices.

Human power can also be more efficiently used in agriculture. High quality, simple tools speed up the work of processing and harvesting crops. Devices such as handpump bring ground water to the surface, making irrigation of small plots possible (while saving time spent searching for water). The more tools and skills a rural farmer has at his or her command, the more productive and profitable the farm is.

In summary, it is up to the young farmers in Kenya today to improve their agricultural output and thus meet the needs of the growing country. Their choices of *modern, affordable* farming tools and methods, and their *creativity* in solving the individual problems will help determine Kenya's future food situation.

This book describes several farming tools and methods which make use of renewable energies for farms. Agroforestry and biogas digesters, in particular, are fuel producing systems which help increase crop production.

Energy: Forms, Conversions and Efficiency

Energy, measured in joules (J), watts (W) or calories (Cal), is defined as the ability to do work. It is not the purpose of this book to explain in detail the physical theories of energy. However, an understanding of a few general principles of energy and a good understanding of energy forms, conversions and efficiency are essential to make use of renewable energies.

Energy Forms

Energy comes to us in various forms, some of which are easier to make use of than others. Five important forms of energy which we make use of every day include *chemical, heat, mechanical, electrical* and *radiant* energy.

Mechanical energy is kinetic energy in moving objects. The turning shaft in a posho mill, a bicycle moving down-hill and running water all contain mechanical energy. Machines accomplish mechanical work.

Chemical energy is the energy stored in chemical bonds between atoms. Wood, maize, petrol and dry cell batteries all contain chemical energy. Fuel energy is stored chemical energy.

Heat energy is the energy in fast moving molecules. A fire gives off heat energy. The brakes of a bicycle, when applied, convert the mechanical energy of the moving bicycle to heat energy on the brake pads. Heat energy dissipates rapidly and is hence difficult to store.

Electrical energy is the energy contained in currents of moving electrons in wires. One of the most adaptable forms of energy, electricity can be used to do many tasks (from lighting to ironing to powering machines). Electrical energy must be converted to another form of energy (i.e. chemical energy in batteries) before it can be stored.

Radiant energy is the energy contained in light waves. Solar energy arrives as radiant energy. Plants make much use of radiant energy by photosynthesis, storing the sun's energy as chemical energy in the form of sugars, starches, cellulose and other organic compounds.

Table 1.5 Comparative Energy Values of Various Chemical Fuels

FUEL	UNIT	ENERGY VALUE (MJ)	LITRES/TONNE
BIOMASS FUELS			
Biogas (60% Methane)	m^3	21.0	-
Producer gas (CO, H_2, CH_4)	m^3	3.6-5.5	-
Ethanol	litre	21.6	1250
Methanol	litre	15.5	1265
Wood (15% MC, 1% ash*)	kg	16.0	-
Crop residues (15% MC, 5% ash*)	kg	14.3	-
Animal dung (15% MC, 20% ash*)	kg	14.5	-
Wood charcoal (5% MC, 2% ash*)	kg	31.5	-
Crop residue charcoal (5% MC, 10% ash*)	kg	28.9	-
PETROLEUM FUELS			
Crude oil	litre	35.9	1165
Deisel	litre	35.8	1192
Gasohol (10% ethanol)	litre	31.7	1333
Petrol	litre	32.8	1343
Paraffin (kerosene)	litre	34.8	1240
Liquid petroleum gas (propane, butane)	litre	25-27	1430
Coal	kg	26-38	-

*Moisture content (MC) and ash content are explained in Chapter 3.

Source: Keith Openshaw, 1987

Conversions

When any work is done, energy is converted from one form to another. Our bodies convert the chemical energy stored in food to mechanical energy (when walking, for example) and heat energy. A *jiko* converts the stored chemical energy in wood to heat and radiant energy. The engine of a moving lorry converts chemical energy in petroleum to mechanical energy and heat energy. A light bulb converts electrical energy to radiant and heat energy.

It is usually easier to convert "higher" forms of energy to "lower" forms of energy than it is to convert lower forms of energy to higher forms of energy. For example, it is quite easy to convert electrical energy into heat energy (using resistors), but much more difficult to convert heat energy into electrical energy. Similarly, it is easy to convert chemical energy into heat energy, but much more difficult to convert heat energy into chemical energy. Heat is often referred to as a low grade energy. There are two rules which govern all energy changes and transfers:

Every time energy changes its state, it changes from its original state to more than one different states. In the case of chemical energy in burning firewood, energy is converted to both radiant and heat energy. In the case of a generator, mechanical energy is changed into both electrical and heat energy. This means that unless we are able to use all of the forms of energy produced, *some of it will always escape unused in any conversion.*

Every time energy is transferred, some of it is lost. If electrical energy is transferred through wires over a distance, some of it is lost as heat in the wires. If mechanical energy is transferred by means of belts or gears, some of it is lost as frictional heat in the gears. If radiant energy is transferred using a mirror, some of the energy is absorbed on the surface of the mirror. If heat is transferred from a fire to a cooking pot, some of it always escapes to the outside air as radiation or in convection currents. These rules describe two types of devices:

Change of state devices which convert energy from one form to another.

Energy transfer devices which move a form of energy from place to place.

Table 1.6: Common change of state devices

Engine	Converts chemical to mechanical energy
Generator	Converts mechanical to electrical energy
Light bulb	Converts electrical to radiant energy
Matches	Convert chemical to heat energy
Electric cooker	Converts electrical to heat energy
Motor	Converts electrical to mechanical energy
Jiko	Converts chemical to heat energy

Table 1.7: Common energy transfer devices

Gears/belts	Mechanical energy
Wires	Electric energy
Steam pipes	Heat energy
Jiko	Heat energy (from wood to pan)

Energy Efficiency

The energy efficiency of any device is a measure of *how much* of the potential energy available is actually used to do a given task. How much of the energy stored in petrol is actually used to power a vehicle, instead of escaping as unburned exhausts? How much of the electrical energy in a wire is converted to *light* in a bulb, instead of escaping as heat?

In this book, the efficiency of many renewable energy devices is given as the *percentage efficiency.* This is the actual delivered energy divided by the total potential energy available times one hundred.

$$\textit{Percentage efficiency} = \frac{\textit{actual delivered energy}}{\textit{total potential energy}} \times 100$$

Efficiency Example 1: A Three Stone Fire

We can find the percentage efficiency of a three-stone fire (i.e. how efficiently the fire uses woodfuel to cook a meal).

Assume that it takes about 700 KJ (0.7 MJ) to cook one kilogramme of *ugali*. This is the actual delivered energy that enters the pan and is used to cook the *ugali*. However, because much heat escapes from the fire without entering the pan it should be obvious that more than 700 kJ of energy is required to cook the *ugali*.

While cooking one kilogramme of *ugali*, 440 grammes of air-dry wood are consumed in the fire. Because air-dry wood contains about 16 MJ of energy per kilogramme we can multiply to find the amount of energy in 440 grammes of wood:

$$\frac{16\ MJ}{1\ kg\ wood} = \frac{X\ MJ}{0.44\ kg\ wood} = 7.04\ MJ$$

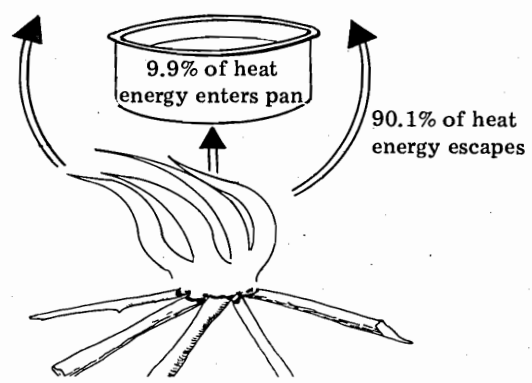
The total potential energy in 440 grammes of wood is thus 7.04 MJ (7,040 kJ). Inserting these numbers into the percent efficiency equation, we can find how much of the total energy contained in the wood is used to actually cook the food.

$$Percentage\ efficiency = \frac{actual\ delivered\ energy}{total\ potential\ energy} \times 100 = \frac{700\ kJ}{7{,}040\ kJ} \times 100 = 9.9\%$$

The three-stone fire in this example is about 9.9% energy-efficient. This means that 90.1% of the energy escapes unused as radiated or convected heat energy.

Some energy-using devices are more efficient than others. The way we *use* devices such as *jikos*, engines, cookers and pumps has a great effect on their efficiency. If we are conscious about which type of energy consuming devices we use and how we use them, we will use less fuel and save money spent on fuel and time spent searching for fuel.

Energy-efficient engines do more mechanical work per litre of petroleum. Energy-efficient light bulbs give off more light per watt of electricity. Energy-efficient *jikos* supply more heat to the pan per kilogramme of woodfuel.



Energy Flow in a 3 Stone Fire

Efficiency Example 2: Comparing Two Types of *Jikos*

Below, charcoal consumption by the traditional metal *jiko* is compared with that of the Kenya Ceramic Jiko (a new efficient *jiko* now available all over Kenya) in order to illustrate the energy savings that can be made using energy efficient devices. As with the previous example, the *jikos* are cooking one kilogramme of *ugali*.

Given Data

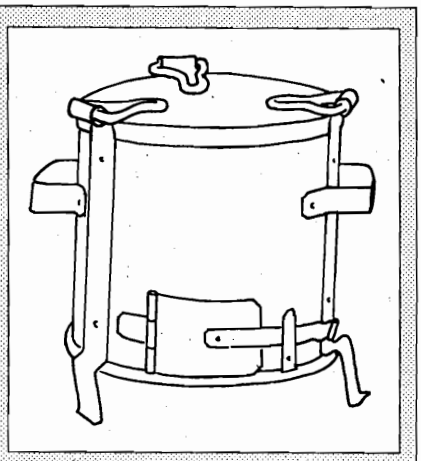
700 kJ of heat must be delivered to the pan to cook one kilogramme of *ugali*.
Charcoal contains 32 MJ/kg (32,000 kJ/1000 grammes) of stored chemical energy.
The traditional metal *jiko* is *20%* efficient
The Kenya Ceramic Jiko is *30%* efficient.

Problem

How much energy (in kJ) does each stove consume in order to cook 1 kilogramme of *ugali* ?
How much charcoal (in grammes) does each stove consume cooking the same *ugali* ?

(Example continued on next page)

The Traditional Jiko (20% Efficiency)



$$\text{Total energy consumed} = \frac{\text{actual delivered energy}}{\text{percent efficiency}} \times 100$$

$$= \frac{700 \text{ kJ}}{20\%} \times 100$$

$$= 4500 \text{ kJ (or 4.5 MJ)}$$

Thus the stove releases 4500 kJ of heat to prepare 1 kg of ugali..

How much charcoal is required to produce 4500 kJ of heat energy?

$$\text{Charcoal contains: } \frac{32 \text{ MJ}}{1 \text{ kg}} \text{ or } \frac{32 \text{ kJ}}{1 \text{ gm}} \text{ of heat energy.}$$

Therefore, using proportions, the amount of charcoal required to produce 4500 kJ of heat can calculated:

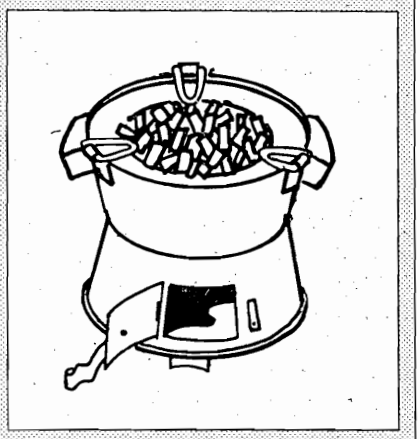
$$\frac{32 \text{ kJ}}{1 \text{ gm}} = \frac{4500 \text{ kJ}}{x \text{ gm}}$$

$$x \text{ grammes} = \frac{4500 \text{ kJ}}{32 \text{ kJ/gm}}$$

$$= 141 \text{ gm of charcoal.}$$

141 grammes of charcoal are thus required to produce 4500 kJ of heat.

The Kenya Ceramic Jiko (30% Efficiency)



Because this *jiko* is more efficient, we would expect it to burn less charcoal than the traditional metal one.

$$\text{Total energy consumed} = \frac{\text{actual delivered energy}}{\text{percent efficiency}}$$

$$= \frac{700 \text{ kJ}}{30\%} \times 100$$

$$= 2333 \text{ kJ (or 2.333 MJ)}$$

The stove puts out 2333 kJ of heat in order to cook 1 kg of ugali. Notice that this amount is much less than the traditional jiko *burns.*

The total amount of charcoal consumed to produce 2333 kJ of heat energy is calculated as above, using proportions:

$$\text{grammes charcoal burned} = \frac{2333 \text{ kJ}}{32 \text{ kJ/gm}}$$

$$= 73 \text{ gm of charcoal.}$$

Indeed, the Kenya Ceramic Jiko, in this example, consumes almost half the energy of the traditional jiko to cook the same amount of food.

The above example demonstrates the potential savings of an improved energy-using device. The Kenya Ceramic Jiko has already saved a great amount of charcoal in this country. Throughout this book, efficiencies of energy devices such as stoves, windmills, hydro turbines and solar devices are given. It should be obvious from this example that efficient change-of-state devices have many advantages over inefficient ones.

Efficiency is not always the most important factor in determining whether a renewable energy device should be used. The hydraulic ram, for example, which pumps water for irrigation or domestic uses, is not very efficient. Neither are most wind pumps or solar electric devices. But hydraulic rams, windpumps and solar cell modules extract useful forms of energy (mechanical or electric) from *plentiful* resources (solar, wind). Most people do not find it necessary to use efficient stoves when wood is plentiful. Efficiency, therefore, becomes more important as energy sources become less available or as they increase in price.

Energy Use in Boarding Schools

Schools in Kenya prepare students for their future vocations. What students learn in primary, secondary and polytechnic schools must be useful to them throughout their lives.

The energy crisis is a major problem facing Kenya today. The Ministry of Education is encouraging teachers to cover this problem in science, home economics, agriculture and industrial arts syllabi (there are many questions on the KCE regarding solutions to the energy crisis). But theoretical knowledge is not enough. Because schools are energy users (and often *energy wasters*) it is important that students learn practically how to solve the energy crisis in school.

Schools are places where conservation and renewable energy projects can be demonstrated on a local basis. Renewable energy solutions should be spread from schools, institutions and polytechnics to communities. In short, schools can lead communities to better conservation practices and renewable energy solutions by practical demonstration.

The ways in which boarding schools meet their energy requirements reflect the way in which the surrounding community solves its energy needs. Where does the wood your school uses to cook with come from? Who carries it? Where does the water come from? What do you use for lighting? As shown below, many schools presently do not make much use of energy conserving practices.

Cooking Meals

Most schools in Kenya use wood for cooking. Some schools gather wood from the nearby bush, and this wood is carried by students (usually girls). Some schools buy wood by the pick-up or lorry. This wood is brought from other areas, and is quite expensive. Very few schools plant trees for their own cooking use.

Schools typically cook their food over open fires or on very simple stoves. Often the cooking pots are uncovered and the cooks make no attempt to save wood. Heat is wasted by inefficient cooking practices. Wood is wasted. Some schools have improved stoves (such as *Alpha Laval cookers*) which help save energy.

Schools in urban areas most frequently use gas for cooking. They may also use wood (if there is a nearby source) or charcoal. Electric stoves are too expensive for institutional use. City schools tend to use better cooking equipment and methods than rural ones because they are concerned about the high cost of their cooking fuels.

Improved institutional stoves such as the Bellerive Institutional Stove offer a way to save significant amounts of money spent on woodfuels. More than 250 such stoves have been installed in institutions all over Kenya (see Chapter 3).

School Water Supply

Depending on their source of water; *rivers, ponds, wells, boreholes, rain catchment or pipes,* schools have various ways of bringing water to the compound.

Many schools have large storage tanks which store rainwater, piped water or pumped water for several months at a time. But, often there is not enough rain or piped water to supply the school's needs.

Most rural students have had to spend some time during their school years carrying water from nearby streams, rivers, wells or water holes. Time spent fetching water might have been spent studying, and the more time spent fetching water, the more lost studying hours.

Diesel pumps are used by some schools to pump water from streams, wells or boreholes into storage tanks, but buying and maintaining diesel pumps is expensive for small schools.

Rain catchment is the most successful water supply method presently in use. Large storage tanks are necessary in areas where rain only falls for a few months. The larger the storage capacity of the tanks, the more study time saved for students.

Lighting and Electrical Equipment

Quality lighting is crucial for the success of night-time studies at boarding schools. Two types of school lighting common in Kenya are (1) *electric lights* powered by mains or generators and (2) *pressure lamps* powered by paraffin. Large schools have mains (if they are near to a town or city) or generators. When mains are very far away, diesel generators used to be the only electrical alternative available. However, they must be maintained and serviced regularly and diesel must be bought and delivered regularly. Over the long term, generators are quite expensive for lighting.

Paraffin pressure lamps are relatively cheap in initial cost. However, they do not last for a long time (~two years). They have many spare parts that must be replaced constantly (mantles, glass covers). The light they give off is neither high quality nor consistent. Aside from the other mentioned problems, pressure lamps are expensive for lighting many classrooms if only the monthly cost of paraffin is considered.

Radio and television offer educational programmes that can broaden the scope of a rural student's knowledge considerably. Slide and film projecters also have valuable potential for educational purposes. Electrical equipment for experiments gives students studying physics, chemistry and biology an advantage in those subjects. All of these must somehow be powered.

Presently, solar electricity powers lighting systems for more than 25 schools in Kenya. Solar and wind generated electricity both have a high potential for supplying small electrical needs such as lighting in remote institutions. (See Chapters 5 and 6).

Hot Water

Institutions need hot water to keep a minimum standard of hygiene. Because many people occupy the same place (i.e. dormitories), diseases can spread quickly if a high standard of hygiene is not kept. Dormitories, showers, kitchens and latrines should be kept clean, and hot water can effectively clean these places.

Most schools in rural Kenya do not make much use of hot water. The hot water that is used is usually heated inefficiently over wood fires. The main reason hot water is not used is because it is too expensive for the limited budgets of small schools.

Improved stoves make it more economical for schools to provide hot water for their students. Solar water heaters have been installed in hundreds of Kenyan institutions to cheaply provide hot water.

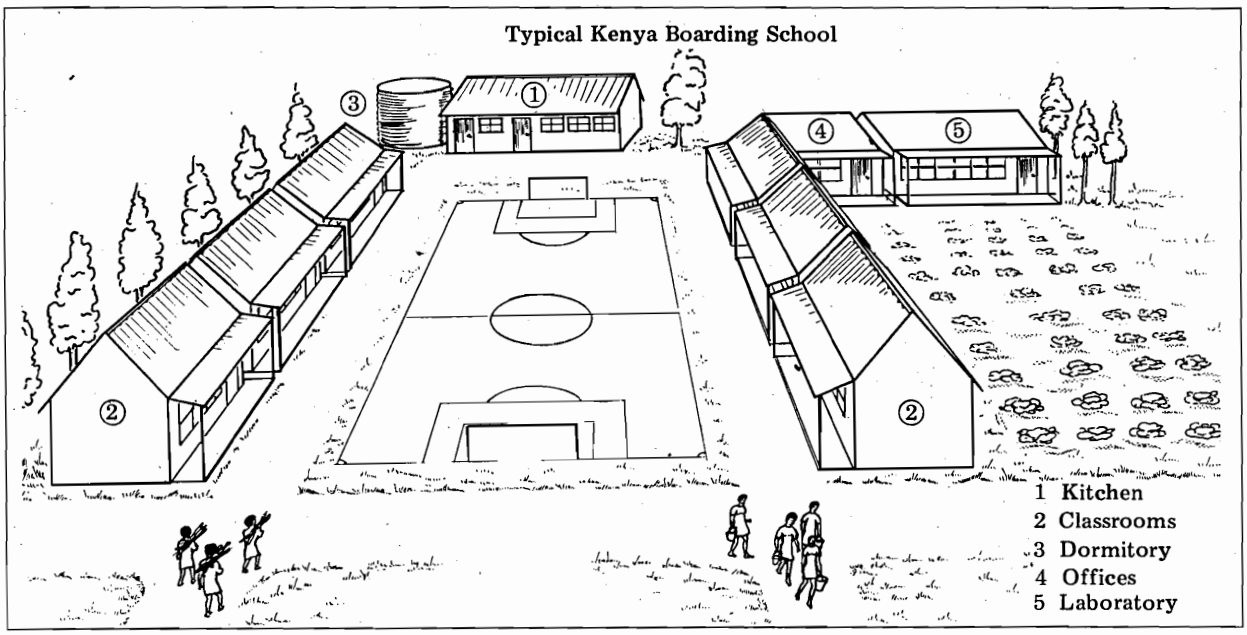


Table 1.8 Energy Use in a Typical Kenyan Boarding School (~100 students)

LOCATION	REQUIREMENT	TOOL	FUEL	AMOUNT
1 Kitchen	Cooking: 3 meals/day	Open fire	Wood	~10 tonnes/month*
2 Classrooms	Lighting: 4 hours/night	Pressure lamps	Paraffin	~80 litres/month*
3 Dormitory/ kitchen	Water supply: cleaning, cooking, showering	Student labour/ rain catchment	Animate/ natural	~2000 litres/day*
4 Offices/ staff houses	Power for small machines	Calculators, radios, projectors, etc.	Batteries	Variable
5 Laboratory	Gas for practicals	Burner	LPG	~1-2 cylinders/term*

*Actual use depends on each school's locality and resources

General Introduction to Renewable Energy 2

Renewable and Non-renewable Energy

People collect various forms of stored energy every day and use them for various energy requirements. We gather woodfuel or we buy charcoal. We buy paraffin for evening lighting. Each form of energy comes from a particular source. Woodfuel comes from trees. Paraffin is refined from crude oil that comes from the Middle East. Mains electricity comes from hydroelectric power stations, geothermal power stations or oil-fired generators.

Sources of energy are either (1) constantly being replaced as they are used or (2) constantly becoming less plentiful as they are used up. Thus, all sources of energy can be divided into two types: *Renewable energies* and *conventional energies* (non-renewable energies). The supply of renewable energies is unlimited over the long term, but the supply of conventional energies is limited. In other words, conventional non-renewable energies will be used up, or *depleted*, eventually.

Conventional Energy Sources

Non-renewable energy sources include fossil fuels, some types of geothermal power and nuclear power. These resources are made by natural processes that take many millions of years. Presently, they are being used by man at a rate that is much faster than the rate at which they are formed. Once they are *depleted* there will be none left. Kenya makes much use of fossil fuels and geothermal power.

Fossil Fuels

Fossil fuels are made of carbon compounds from organisms that were living many thousands of years ago. Changes in the earth's surface, sedimentation and high pressures underground *fossilised* ancient plant remains. Thus, biomass is changed into petroleum compounds over many centuries. Deposits of underground fossil fuels are found in such parts of the world as the Middle East and North America. Unfortunately Kenya has no known deposits of fossil fuels on its land.

There are three forms of fossil fuels that can be found naturally: solid, liquid and gas. Kenya makes most use of liquid fossil fuels distilled from crude oil. Paraffin, petrol, diesel, motor oils and jet fuel are all made from crude oil. Kenya's transport industry depends on liquid petroleum products.

Fossil fuels are also found underground in the form of gases. *Natural gas* is the name for the gas that is piped to the earth's surface and used for cooking and heating. Natural gas, made of mostly butane and propane gases, is liquified under pressure and stored in metal cylinders. These cylinders are sold in Kenya as Liquified Petroleum Gas (LPG).

The most common solid form of fossil fuels is coal. Kenya imports coal (the cheapest fossil fuel) for use in the manufacturing of cement. Coal is commonly used for heating in cold climates. Tar sands and oil shale, from which petroleum products can be derived, are two solid forms of fossil fuels that are found in Kenya.

Geothermal Power

Geothermal power makes use of heat energy from the mantle of the earth stored in underground pockets. Bodies of steam collect underground at high temperatures (150-400°C) in certain parts of the earth's crust. This steam, if tapped, can be used to drive turbines that generate electricity. It can also be used to provide heat for drying or other industrial purposes.

Geothermal power can only be tapped in certain areas. These areas usually are places where there has been some history of volcanic activity. In places such as the Rift Valley, heat flow from the earth's mantle to its crust is much greater than normal. The Olkaria Geothermal Plant near Nakuru, an example of such a place, supplies almost 20% of Kenya's electricity.

Once an appropriate site is found, holes are drilled into the underground steam source. A power station with turbines is constructed on top of the steam vents, and the electric power generated is then carried by the grid to places where it is needed. Because there are a number of sites from which geothermal power can be extracted in Kenya, the government has plans to install several more geothermal power stations for electrical generation.

Nuclear Power

Nuclear power harnesses the immense amounts of energy found inside the nucleus of certain radioactive elements. The power generating process requires uranium which is found in South Africa, North America and Asia as a raw material. Nuclear power plants produce large amounts of electricity, but they are very expensive and technologically advanced. They also produce a hazardous radioactive waste which is difficult to dispose of. Because of the hazards, the high technology required, and the large expense, nuclear power plants will not be feasible in Kenya in the near future.

Renewable Energies

Renewable energies are the result of various forces constantly at work in our environment. The regular heating and cooling of the earth's atmosphere by the sun causes movements of high energy wind. Rain water and spring water fall and move downhill releasing much energy on their trip towards the ocean. Forests and crop land capture energy from the sun by photosynthesis and store it chemically in wood and food crops. Direct sunshine radiates the earth with much energy which is felt as heat. Solar energy powers all of the weather cycles on earth, and thus all renewable energies can be traced back to the sun.

Biomass Energy

Green plants use solar energy to chemically convert carbon dioxide and water into sugars in the process called photosynthesis. These high energy sugars are stored in the organic material called *biomass* that makes up the bodies of all living things. Wood, charcoal and animal waste are important biomass fuels.

Wind Energy

Wind results from movements of the atmosphere which are caused by uneven heating and cooling of the earth's surface. At any given time, half of the earth's surface is being heated by the sun. The atmosphere warms and expands on the sunny side of the earth. Meanwhile, the atmosphere on the dark side of the earth cools and contracts. Interactions between these cooling and heating air masses over the oceans and continents produce moving currents of air which contain large amounts of energy. Wind energy is captured and used by sails on boats or by windmills.

Hydropower

The water cycle unleashes vast amounts of energy. Water heated by the sun evaporates from the surface of oceans and lakes. This water vapour rises and forms clouds. Clouds store energy in the form of condensing rain water which falls, collects in streams and rivers, and is pulled towards sea level by gravity. The energy contained in moving water can be harnessed in huge applications such as hydroelectric dams or in smaller applications such as hydraulic rams.

Direct Solar Energy

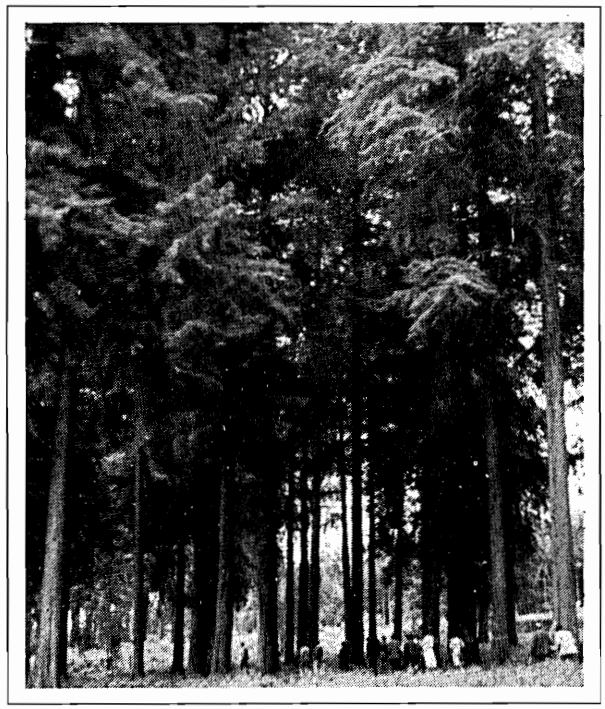
Biomass, wind and hydro power are all indirect forms of solar energy. The solar radiation (sunshine) that falls upon and heats the earth's surface is also an important renewable energy. Direct solar radiation shines upon exposed objects, and they absorb the radiation and heat up to produce useable energy. Direct solar radiation has long been used to dry food crops, clothes and animal skins. Kenya has more direct solar energy than most countries because it is located on the Equator. Direct solar energy has the potential of serving much of Kenya's heating and electricity needs.

The Supply of Renewable Energies

Renewable energies are constantly being produced and their long-term supply is great. However, they can only be used as fast as they are generated. Wind energy can only be used at the rate the wind blows. Hydro power can only be used at the rate that streams flow. Solar energy can only be harnessed at the rate that the sun shines.

If there is no wind in a certain area, wind energy is not a very good choice as a source of energy. If there are no fast moving rivers or streams, hydro power is not an option. If it is cloudy most of the time, direct solar will not help solve energy problems.

Is woodfuel a renewable energy? Energies are only renewable if they are used at a rate that is the same as or lower than the rate they are generated. However, in Kenya trees are now being cut down faster than they can grow. Wood energy sources are not able to renew themselves. More trees must be planted and cared for and forests well managed if wood is to be considered a permanent renewable resource in Kenya.



Cypress plantation at Moi University, Eldoret. Good management of forests and plantations will make wood a permanent renewable resource.

Why Renewable Energies Are Appropriate For Rural Areas

Renewable energies make use of local resources. Renewable energy (RE) systems harness biomass, sunlight, wind or moving water. Depending on what is locally available, various systems can be used. Many REs are adaptable so that they can make use of a variety of local materials. Local labour is also used extensively to manage RE systems. The most successful renewable energy projects make maximum use of local materials and labour.

Renewable energies increase rural employment opportunities. Construction and maintenance of REs demand the involvement of many people. REs often require specialised skills and therefore many people are trained and employed to manage them. This creates employment in rural areas.

They help protect the environment. Renewable energies do not pollute the environment. Wind, hydro and solar energies are clean sources of energy. Solar energy can be used to replace wood energy presently used for heating and cooking, reducing the strain on tree resources. Biogas digesters help protect the environment by producing a fertiliser which improves the quality of the soil.

Renewable energies save foreign exchange. At present, a large portion of Kenya's foreign exchange is spent purchasing petroleum. Any renewable energy which replaces a need now served by petroleum will save Kenya money. Solar water heating replaces oil-fired boilers. Wind powered pumps replace diesel generators. Solar electric lights replace paraffin lighting. Biogas replaces LPG gas. The more renewable energies in use, the greater the foreign exchange savings.

Renewable energies can meet demand scattered over large areas. Because they make use of local resources, REs are appropriate for areas that are far from the mains or petrol/diesel/paraffin pumps. Power sources such as solar electricity or windmills are more reliable than power distributed over long distances by lines which may be knocked down during storms.

Renewable energies improve the standard of living. REs save work such as collecting firewood and carrying water, thus enabling people to do other useful work. They also provide cooking gas, lighting, hot water, and/or power for milling and grinding machines. The services and products provided by renewable energies can make an area more self-sufficient.

Biomass Sources of Energy

Biomass fuels are organic materials that can be burned or fermented in order to make use of the chemical energy they contain. Examples include wood, charcoal and plant wastes which are burned directly as fuel, and animal wastes and sugar cane juice which are fermented to produce burnable fuels. Biomass fuels are products of photosynthesis, a plant activity that stores solar energy. Thus, all biomass energy has its origin as solar energy.

Fuelwood and Charcoal

Woodfuel (fuelwood and charcoal together) is Kenya's most important source of energy. More than 70% of the country's energy is directly supplied by fuelwood or charcoal. In rural areas, woodfuel cooks meals, heats water and provides space heating during the cooler seasons. In urban areas, most people cook with charcoal, a wood product. Both large and small industries use woodfuel to provide heat needed for various processes.

Woodfuel energy is considered renewable because the trees that are cut down for use as fuel can be replaced by other growing trees. Branches cut for use in fires grow back. Historically, there were no shortages of wood because trees in forests replaced themselves faster than they were cut.

However, growing populations demand increasing amounts of wood energy. Today in Kenya, trees are being cut down at a faster rate than they can grow. Woodfuel has become scarce in many parts of the country. As forests are cut down faster than they can replace themselves, wood energy resources are being *depleted.* It is increasingly important for people to manage wood energy sources so that woodfuel remains renewable.

Collecting fuelwood in Machakos. As firewood becomes scarcer people must spend increasing amounts of time searching for it. The task of collecting firewood falls heavily upon women and small children.

Making proper use of woodfuel as a renewable energy in order to ensure that there is always enough woodfuel for everyone involves two separate tasks: Increasing wood energy supplies and using wood and charcoal fuels efficiently.

Increasing Wood Supplies

To increase wood supply, trees must be planted to replace those that are cut down. The cutting of forests, plantations, and trees on farms must be well managed so that optimum use is made of them.

Planting trees for use as woodfuel is a task for both the government and individuals. The government sponsors tree planting projects and nurseries all over the country. Schools, churches, youth groups, women's groups and individuals should become more involved in tree planting in order to meet the energy and environmental needs of the country. Small tree planting efforts are just as important as large ones.

Anyone can plant trees. Tree planting does not require special resources or formal education. Many Kenyans have been successfully planting trees for a long time. With a little knowledge, leadership, determination and a lot of care, a tree planting programme will succeed.

A basic knowledge of *forestry*, the science of planting and managing trees and forests, is necessary for those directing tree planting projects. Forestry can be divided into *pure forestry*, which uses trained forestry workers to manage forests and plantations efficiently, and *social forestry*, which is farm or community-level forestry carried out by members of the community.

Pure Forestry refers to the scientific growing of trees on a large scale (typically hundreds of thousands of acres). In Kenya, pure forestry work is carried out by both the government and a few private companies. Pure forestry principles are applied in the management of tree plantations that produce timber for construction, wood pulp for making paper and woodfuel for commercial uses. Foresters carefully manage these plantations so that the maximum amount of wood can be harvested from them.

The management of Kenya's Gazetted Forest and Woodlands (less than 3% of the total land) is the principal government activity in pure forestry. Thousands of hectares have been planted with eucalyptus, cypress and pines to provide timber and paper for the country's needs. As well, the government manages the country's natural forests. Many of the trees in these forests, have valuable wood. Camphor wood, for example, makes excellent furniture while other woods are valued for carving. Foresters make sure that these trees in national forests are not cut down faster than they can grow. They issue licences which regulate the rate at which trees are cut down, ensuring that the forest will be able to replace those trees which have been cut.

Social Forestry, the planting of trees at the individual or community level, has been practised in Kenya for a long time. From traditional times, farmers have known the value of trees. Today, 40% of the woodfuel in Kenya comes from trees on farmland. Trees are planted by rural farmers because trees benefit the farm. They improve the soil, provide fodder, timber and poles for building, and nutritious fruits in addition to woodfuels. The most important goal of social forestry programmes is to link the needs of rural people with the wide range of useful products which trees can provide.

It is not enough to tell a farmer to plant trees. Most people already know that we should be planting trees. Social forestry teaches *why* trees must be planted, *how* we should organise nurseries and planting projects, *which* trees are best for each situation and *when* and *where* we should plant them.

Social forestry programmes involve four components; education and motivation of people to get them to plant trees, organisation of tree planting schemes, the establishment of tree nurseries and the actual planting and caring for trees. The last component, planting and caring for trees can be carried out in a variety of ways as described below.

Community Woodlots are planted on communally-held land to supply fuelwood, poles or timber to the community. Such woodlots require a lot of work and organisation. Before attempting to start a community woodlot, a good plan should be made which includes the care of the woodlot and the long-term distribution of the wood products.

Agroforestry is a land-use system in which farmers grow both trees and crops on the same plot in a way that is scientifically sound, practically feasible and environmentally desirable.

Tree nursery in Murang'a. All successful tree planting projects start with well run nurseries that supply tree species demanded by the community.

Planting trees on individual farms has proved to be very effective. Farmers are more likely to care for trees which have been planted on their own land for their own use. Agroforestry methods enable farmers to make better use of their land. Certain types of trees are grown for different applications. Below are proven agroforestry methods commonly used on Kenyan farms:

-- Boundary Planting is traditional planting of trees along property boundaries and roads. Boundary planting provides wind breaks, shade along paths and privacy for compounds in addition to its basic use as a permanent marker for property limits. Fast growing fuelwood trees, hedges and ornamental trees are commonly used for boundary planting.

--Woodlots are planted on agriculturally unproductive land (rocky , infertile land etc.) to provide timber, poles and woodfuel that can be used or sold by the farmer.

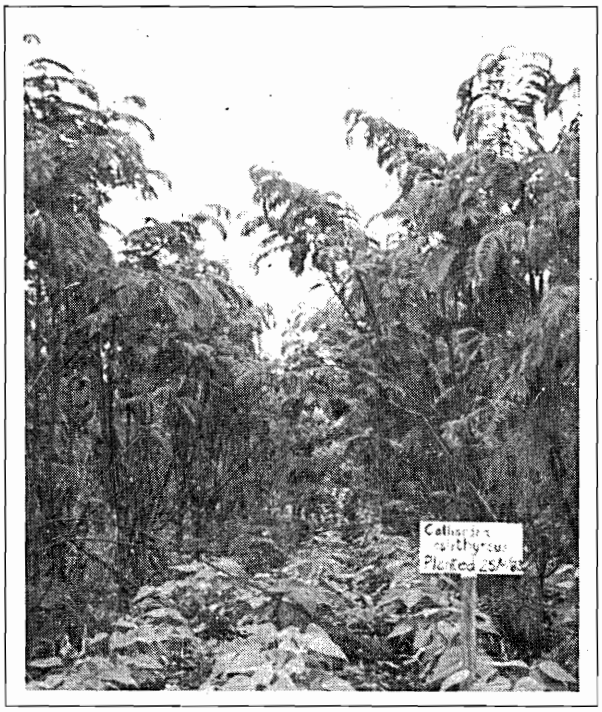
-- Hedgerow (Alley) Cropping is the interplanting of rows of trees with rows of crops. Leguminous shrubs are useful for hedgerow cropping because they fix nitrogen (making the soil more fertile) and can be coppiced regularly for firewood. Many trees add humus to the soil (in the from of shed leaves) and improve the soil's water retention capacity.

--Trees planted around the house provide shade that cools the compound area, fruits rich in vitamins, beauty from seasonal flowers, and windbreaks.

Using Fuelwood Resources Efficiently

Increasing the amount of fuelwood by planting trees and managing existing farm trees, forests, plantations and woodlands is only part of the solution to Kenya's fuelwood crisis. Population growth causes the demand for fuelwood to rise very quickly. Tree planting efforts alone cannot keep up with the growing demand for wood products.

Tree planting must be accompanied by *woodfuel conservation.* If Kenya is to remain forested, the available woodfuel must be used as efficiently as possible. Making the *best possible use* of the energy in each bundle of wood and each bag of charcoal will save many trees.



Alley cropping with Calliandra calothyrsus *at Jamhuri Agroforestry Centre.*

Many people in Kenya already feel the need to conserve fuelwood. The days when people did not have to worry about wasting energy while cooking and heating water are over. Collecting fuelwood may take many hours each week. Buying charcoal is expensive.

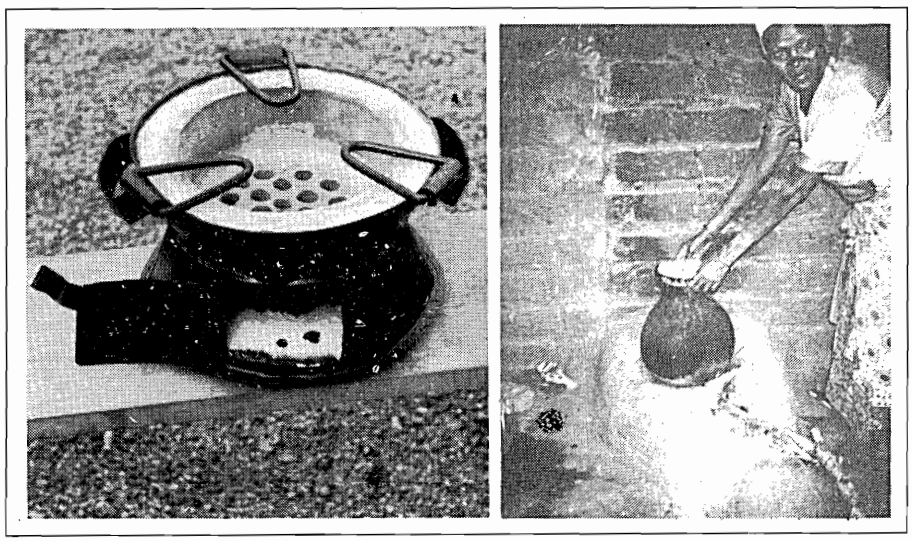
There are three ways in which woodfuel resources can be used more efficiently: using energy conserving stoves; using improved kilns and kilning methods to make charcoal; and by improving kitchen management.

Energy Conserving Stoves and Jikos.

Traditonally, most Kenyans cook with wood over *three-stone fires.* These fires cost nothing, require few skills or tools to build, are movable and can burn many types of fuel. They also can fit any sized pot, provide light and space heating, and can easily be controlled. Three-stone fires, when used properly, may have more advantages than improperly used "energy conserving" stoves.

But, three-stone fires are often not efficient cooking devices because they lose much heat to the surroundings. Hot gases flow upward without transferring any of their heat into the pot. If the open fire is blown by wind it burns rapidly and wastefully.

Improved stoves that suit



Improved stoves such as the charcoal burning Kenya Ceramic Jiko (left) and the Maendeleo stove (right) are now being used in households all over Kenya. Combined with energy efficient cooking methods, these stoves can cut fuel use in half.

the needs of rural people have been developed in Kenya and the rest of the world. These stoves contain the heat of the fire, direct it onto the cooking pot and control the rate at which the fire burns. They are made cheaply from locally available materials (i.e. clay or stone) and are built by trained local craftsmen. They not only save wood and create rural employment, but they also bring several important benefits to the kitchen. Stoves reduce the fire's smoke output, make the kitchen cooler during the hot times of the day, and reduce dangers of accidental burns to children and fires to the house. There are many different designs for improved stoves that use energy efficiently. However, those that are successful are the ones that suit the needs of the user as best as possible.

Pictured are several examples of improved stoves that have been adopted by households, institutions (like schools, prisons and colleges) and industries that use woodfuels.

Improved Charcoal Production Technologies. Charcoal is the most important urban cooking fuel in Kenya. The demand for charcoal is increasing at about 7% per year as more and more people migrate to urban centres. Charcoal is preferred to fuelwood by people in urban areas for many reasons. It has twice as much energy per unit weight; it burns at a higher temperature than wood; it produces less smoke than wood; it is easier to manage in a "jiko"; and it takes up less space so it is easier to sell, transport and store. Presently, almost all of the charcoal used in Kenya is made by traditional methods. However, because traditional earthmound or pit kilns use much wood in the production of charcoal, they waste fuelwood energy. Methods of charcoal production must be improved so that as little woodfuel as possible is wasted.

The process by which charcoal is made from wood is called *carbonisation* (or *pyrolysis*). Carbonisation of wood occurs when it is heated to high temperatures in the absence of oxygen. Kenya's charcoal-makers apply the principle of carbonisation when using the simple earthmound kilns and pits that they build near the place where they have felled trees. Although traditional methods of making charcoal are wasteful, charcoal-makers can make many bags of charcoal cheaply in earthmound pits.

However, one tonne of charcoal contains only about one quarter of the energy of the woodfuel from which it is made when produced in traditional kilns. In 1980, Kenyans used about 1.4 million tonnes of charcoal and between 10 and 14 million tonnes of wood were used to produce that charcoal. If more efficient kilns or kilning methods are used in charcoal production, then very many trees will be saved.

Improved charcoal making technologies have several important benefits. The first is higher charcoal production efficiency. Traditional earthmound kilns have a yield of about 8-13%. This means that for every 100 kilogrammes of fuelwood used in the charcoal making process, only about 8-13 kilogrammes of charcoal are produced. Improved kilns are much more efficient. The half-orange brick kiln (which has been used successfully in Kenya) gives yields of more than 25%. With this type of kiln, twice as much charcoal can be produced from the same fuelwood that would be used in an earthmound kiln.

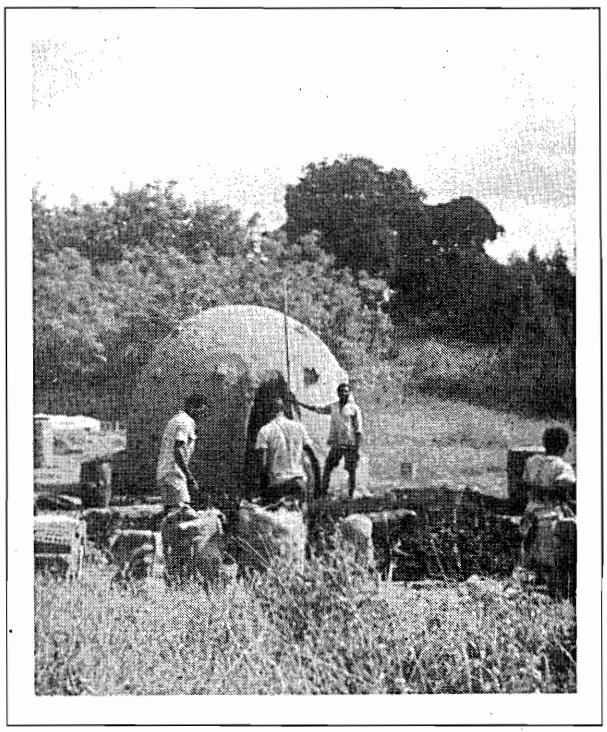
Charcoal production technologies can be divided into three categories:

-- Earthmound kilns and charcoal pits. These methods have been used traditionally in Kenya and most parts of the world. Although they are wasteful, their advantage is that they cost the user very little to build and can be built anywhere. However, they need skilled operators to run them properly.

-- Brick or metal kilns. These kilns are more efficient than traditional methods and the charcoal they produce is free from dirt and sand. Some metal kilns are portable and can be carried to their place of use. The disadvantage of these kilns is that they cost money to build. Also, since they are usually fixed, wood has to be transported to their site.

--Retorts have an external heat source which may burn the gas products (producer gas) made during pyrolysis. Their advantage over kilns is that they allow collection of the gas and oil by-products of pyrolysis. They are also much more efficient than simple kilns because they permit better control of the process. Retorts, however, are very expensive, and are not a technology applicable to the small-scale charcoal producer.

Several types of improved kilns have been introduced in Kenya. However, because of their initial expense, the lack of extension education facilites, and other factors, Kenya's charcoal-makers continue to use traditional methods. One project in Machakos has demonstrated that improved, locally built brick kilns can produce charcoal efficiently and profitably.



Half orange kiln, Mtwapa. Improved kilning techniques can double charcoal yields over traditional methods.

In Senegal, the *'Casamance kiln'* has been widely adopted by charcoal-makers because it is an improvement on the traditional design which significantly increases charcoal yields.

Charcoal can be made from other biomass besides wood. Even biomass that is normally considered as waste (such as coconut shells, coffee husks, rice husks, paper, sawdust and bagasse) can be converted by pyrolysis into charcoal. The Kenya Planters Co-operative Union (KPCU) found out that charcoal briquettes could be made from coffee husks, and they have been selling Kahawa coal in Nairobi markets. Furthermore, charcoal has been made from coconut shells in simple locally-made retorts in Kilifi.

Energy-wise Cooking Methods. Those who cook in Kenya should be taught to use energy-efficient cooking methods in order to conserve wood resources.

Energy conservation starts in the kitchen, be it in the household, institution or the restaurant. Much of the burden of wood conservation falls upon the women and men who cook our daily meals.

Because wood energy is becoming scarce and more expensive, most women have already made some attempts to conserve fuel while cooking. They use the exact amount of fuel required to cook each meal. They tend the fire carefully so that the correct temperature for cooking each meal is maintained. If the fire is still burning after a meal is cooked, they use the energy to make tea or to heat water for a bath. Much can be learned about energy conservation from some women who have never been to school.

The Ministry of Energy and Regional Development has prepared useful guidelines for fuel conservation in the kitchen. They are discussed in detail in chapter 3.

In general, there are three ways to save fuelwood:

Carefully choose and prepare woodfuel. Dry wood for several months before using it. Use wood instead of charcoal whenever possible.

Construct fires carefully. Use only enough wood necessary to do the cooking job. Protect fires from being blown by the wind.

Cook food using energywise methods. Always cover food which is cooking. Prepare food carefully for fast cooking. Several cooking techniques such as the hay box cooker can cut back tremendously on woodfuel consumption.

Biogas Digesters

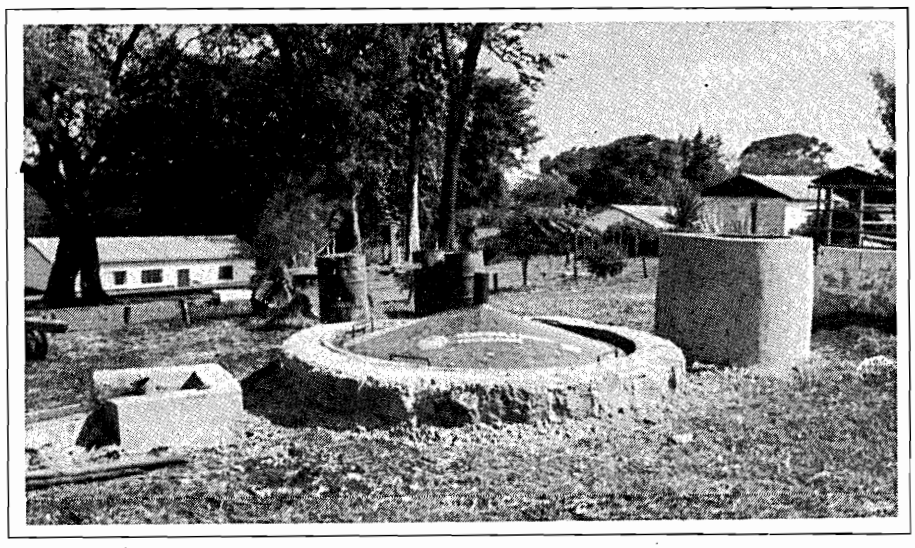
Biogas digesters produce methane gas, a renewable energy, and are also very important farm tools. High quality fertiliser for the fields and methane gas for cooking and lighting are produced by biogas digesters from agricultural wastes available on the farm. Biogas digesters are relatively easy to operate and maintain, and can be built by locally trained masons using local materials. Because of the high number of cattle and livestock found in Kenya's farming areas, biogas digesters have a good potential for supplying *fertiliser* and *energy* in the country.

Biogas is a combustible mixture of methane and carbon dioxide gases. It is produced by the decay of certain organic materials in the absence of oxygen. A biogas digester is a large enclosure which maintains the conditions under which biogas is produced and stores the gas for later use. Decaying materials which are commonly used to produce biogas are cow dung, pig wastes, chicken droppings, rice husks, straw and coffee pulp.

Biogas digesters provide 3 important benefits to rural farms. They increase *sanitation* standards by removing wastes from livestock sheds, thereby reducing the number of flies, worms and disease organisms that live and breed in the boma. Secondly, they improve the qualities of manure or other wastes as *fertilisers.* Finally, they produce a clean burning *gas fuel* that can be used for cooking, lighting and running engines.

Biogas digesters are used extensively in China to promote sanitation and to make fertiliser. Many thousands of digesters have also been built in India to help solve that country's fuel shortage and to produce fertiliser. In Europe, many large towns have used biogas digesters in sewage treatment plants. Biogas technology has spread to many countries in the warmer parts of the world.

The first Kenyan biogas plant was built during the 1950s, and since then hundreds more have been built (not all of which are now working). By 1986, about 250 digesters were operating throughout the country, especially in the Western and Central Provinces. The Ministry of Energy and Regional Development has trained masons to build digesters in Meru, Kisii, Nairobi and Mtwapa, and most of those have built digesters in their areas. Biogas digesters will become more common in Kenya as more people become aware of their many benefits.



Biogas digesters such as this one at Limuru Boys Centre provide farmers with high quality fertilisers and gas that can be used for cooking, lighting and running engines.

Other Uses of Biomass for Energy

Woodfuels and biogas have been discussed as sources of energy. However, other biomass materials (many of which are wastes) can be used as energy sources. Biomass wastes produced in large volumes in Kenya include bagasse, coffee husks, tea wastes, coconut shells and coir, rice husks, maize cobs and saw dust.

Biomass wastes may be used as fuels, fertilisers or animal feed. For example, animal wastes and coffee pulp are returned to agricultural land as fertilisers. Maize stalks and cobs are fed to livestock. Kenya Breweries sells brewery wastes to dairy farmers as feed.

If biomass is used as a fuel it can be *burned directly*, *carbonised* into briquettes of charcoal, or *fermented* to produce alcohol or methane.

Burning Biomass Directly

Local industries burn biomass wastes to produce heat in a number of manufacturing applications. The sugar industry gets all of its process heat by burning *bagasse*, the dejuiced sugar cane stalk. The Pyrethrum Board of Kenya uses waste sawdust from local sawmills in Nakuru to meet its energy needs.

The *Wonderstove*, made by a local Nairobi company, cooks food using biomass wastes such as rice husks, saw dust, wheat husks and tea wastes. Heating biomass wastes inside the stove causes them to decompose and give off volatile gases which burn to cook food.

Carbonising Biomass

Some biomass wastes are carbonised and pressed into charcoal briquettes which are sold in urban markets. Coffee husks, as mentioned before, are made into briquettes and sold in Nairobi. Coconut and macadamia nut shells have also been carbonised to make charcoal locally. In Burundi, *peat* is kilned to make charcoal briquettes.

A major drawback in this use of biomass is that they contain *high ash* and thus do not have as high heat per unit value as wood charcoal.

Fermenting Biomass

Certain biomass materials (sugar, molasses) are fermented and distilled to produce ethyl alcohol, which can be mixed with petrol to make the motor fuel *gasohol*. Currently, alcohol is being produced at a rate of 60,000 litres per day in Muhoroni, Kisumu. The alcohol is used to supply Nairobi's motor vehicles with gasohol.

There is potential for developing other biomass "energy crops" in Kenya which could be fermented to produce alcohol. Two promising crops are cassava and sweet sorghum.

Potential energy uses of alcohol (besides gasohol) include replacing paraffin in modified cookers and lanterns.

Direct Solar:
Capturing and Using Solar Radiation

Solar energy technologies make direct use of the energy in sunlight to provide *heat* or to generate *electricity*. Solar devices that collect heat energy from the sun use this energy to heat water, dry crops and timber, warm homes and even cook meals. Devices that use direct solar energy to produce electricity are used for powering water pumps, refrigerators, lights, electric fences, and household appliances.

Traditional and Established Uses of Solar Energy

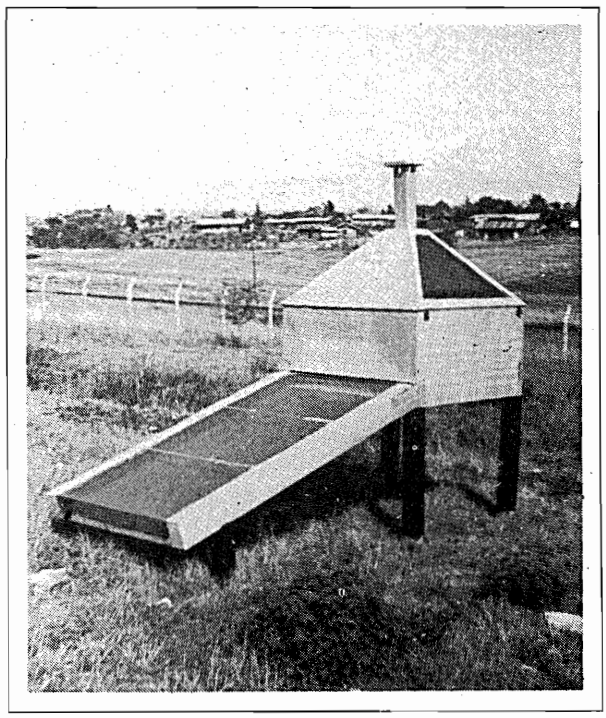
Because Kenya is located along the equator, it gets more solar energy than most other countries in the world. Kenyans have traditionally made use of solar energy for drying crops, fish and various other products. Maize, beans and rice are commonly left in the fields to be dried by solar energy. Fish are dried in racks outside and thus preserved by solar energy. Animal skins are staked out to be dried and cured by the sun. Many people have long used solar energy to dry fuelwood so that it burns with less smoke.

Today solar energy plays a role in the economy that is often overlooked or taken for granted. Some agricultural industries (such as the coffee industries) rely on solar energy for drying their products. Solar evaporation pools make salt from sea water. Many brick-makers use solar energy to dry their bricks. Furthermore, the fact that millions of Kenyans rely on direct solar energy to dry their clothes is hardly ever mentioned.

Uses of Direct Solar Energy

Solar heating devices capture solar energy and make the energy available as heat.

Solar electric devices convert solar energy into



Solar crop drier, Kenyatta Appropriate Technology Centre. Proper drying is vital in preventing storage losses to food crops.

electricity which can be used directly or stored in batteries.

Solar Driers. The traditional practice of leaving crops in the field to dry has several disadvantages. It takes a long time for crops to dry in open fields. During this time crops can be attacked by birds, insects or animals. They can also be spoiled by rain. Solar crop driers speed up the drying process while protecting the crops from damage by insects, animals and rain.

There are several types and applications of solar driers. All of them use air that has been heated by the sun to dry the product. One simple type of solar drier is a raised bin with a tin roof and wire mesh walls. Air flows through the wire mesh, having been heated by the sun, slowly drying the crops inside. This simple drier which has been used for maize drying in Kenya, protects and stores crops while they dry.

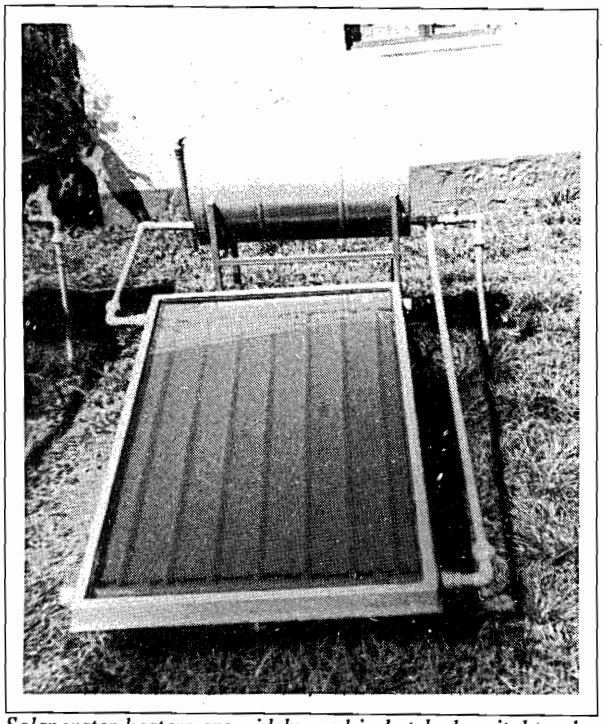
A second type of solar drier relies on the principle of convection: *hot air rises.* Solar energy is used to heat air which rises through a box in which the products are located. Solar energy is trapped as heat in a *flat plate collector.* This trapped heat is transferred into air which rises into the box where the drying crops are located.

Solar Water Heaters. Technologies that use the sun's energy directly to heat water are simple and widespread. Use of solar water heaters saves electricity, wood or oil which would have otherwise been used to heat water. Many hotels, hospitals and individual homes in Kenya now make use of solar water heaters because of their economic advantages.

There are two main parts in a solar hot water system, the flat plate collector and the hot water storage tank. They are connected by pipes which circulate the water. Like solar driers, solar water heaters operate by the principle of convection. When liquid or gases are heated, they rise. Water is heated in the flat plate collector and as it warms, it rises into the storage tank which is located above the collector. The movement of water, driven by solar energy, is called *thermosyphon* circulation.

Solar Stills. Solar stills use the sun's energy to distill pure water from brackish or salty water They are used to produce clean drinking water in places where the source of clean water is limited. Clean water for human consumption is the most important health need worldwide. Certain coastal communities face drinking water shortages because their wells have become salty. Boreholes are often contaminated or brackish in places such as Northern Kenya, and their water is undrinkable. Solar stills are useful in places where the supply of water is unfit to drink.

A solar still is made of slanting glass or plastic solar collectors which are placed above a shallow tray of impure water. Incoming solar radiation heats the inside of the still. The temperature inside the still rises and water evaporates from the tray. This vapour rises, comes into contact with the glass collector, which is *cooler* than the air inside the still, and *condenses* into water *droplets.* Condensed water droplets trickle down



Solar water heaters are widely used in hotels, hospitals and institutions all over Kenya.

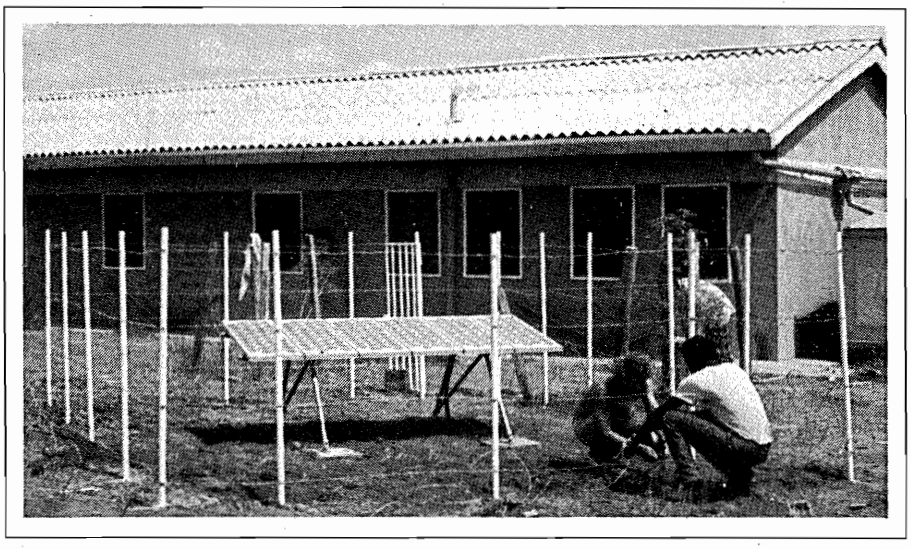
the inside of the glass and fall into gutters. These gutters carry distilled water in to a storage tank.

Solar Cookers. Solar cookers are devices that use the heat energy of the sun to prepare meals. Solar cookers either *capture* and *concentrate* heat from the sun in a black painted box oven or they *reflect* and *concentrate* heat from the sun directly onto the cooking food. These devices offer an alternative to wood in areas where fuel is scarce and sunshine is plenty.

Parabolic solar cookers use large hemispherical reflective surfaces (such as mirrors or shiny metals) to collect, direct and concentrate the sun's rays. The parabolic mirror focuses all of the incoming solar energy onto one spot. The pan of food is placed so that all of the reflected solar energy strikes the pot. As the sun moves across the sky, the mirror is turned occasionally to face the sun.

Another type of solar cooker is the solar box oven. This consists of a sealed and insulated box which has a glass cover on one side. Flat mirrors arranged outside the cooker reflect solar radiation through the glass. This radiation is absorbed by the black painted surfaces inside as heat. The temperature rises inside the box and food cooks slowly. Solar box ovens are simple to make, but their disadvantage is that they can cook only *slow cooking* foods (such as *githeri*).

Solar Electric Devices. Solar electricity is electric power generated directly from sunlight using *solar cells.* Solar cells, thin slices of specially treated silicon, operate by a principle of light called the *photo-electric effect.* When certain materials are placed in light, they transform the light energy into electrical energy. Solar cells generate an electric current when exposed to the sun's rays. This electrical energy can be used to do work directly, or it can be stored in batteries for later use. Solar electricity is ideal for small, remote



Solar electric dispensary, Mandera district. Solar electricity powers lights, water pumps, communication devices and refrigerators in hundreds of remote sites in Kenya.

electrical applications because the electric generation involves no moving parts, no fuel, and very little maintenance. Also, solar cells last a very long time.

The main part of any solar electric system is the *solar cell module*. A solar cell module usually consists of many solar cells connected in series and protected between glass and plastic. Positive and negative leads are located at the back of the module, and electrical loads are attached to these wires. As long as the sun is shining on the module an electric current passes through the wires.

There are other important parts of solar electric systems. If the electrical power is needed at night, then it must be stored, because solar cell modules do not generate electricity at night. Some type of battery must be used for electrical storage. Control panels regulate solar electric systems. They protect the battery from being overcharged or over-used and they indicate whether the solar cell modules are working.

Solar electricity has a number of applications. Calculators and watches often use tiny solar cells to generate power for their small electrical needs. Houses and schools use solar electric systems to power lights, radios and televisions. Remote hospitals and dispensaries use solar electric refrigerators and lights. Solar electric pumps lift water for irrigation and domestic purposes. Solar electricity is fast becoming the most common solar technology.

Small Scale Hydropower

Large amounts of energy are contained in fast-moving rivers and streams. Water expends energy as it flows toward the ocean. This energy is harnessed and used to do work. A large portion of Kenya's electricity already comes from Tana River hydropower stations. Generators along the world's major rivers are large and important sources of electricity. There are also many useful small hydro-power applications.

Small scale hydropower installations are located along fast-flowing streams or waterfalls. The power they make available suits the small mechanical or electrical needs of a nearby individual or community. As long as the stream is flowing, power is continuously available in a predictable, concentrated form. Water powered machines are economical because they last a long time, require few basic maintenance skills, and have low running costs.

The amount of power available from a stream or river depends upon the height from which the water is falling (called the *head*) and the speed at which the water is flowing (the *flow rate*). If the stream's head and flow rate are favourable, then considerable energy may be available for either mechanical or electrical use. Water wheels and hydraulic rams use hydropower to accomplish mechanical work such as grinding and pumping water. Turbines use the energy in fast-moving water to generate electricity.

Most hydro-power devices require water to be diverted by channels and/or stored in dams so that its energy can be conveniently harnessed. This means that the topography and geology of the site must be evaluated before a hydro-power plant is installed. Smaller projects always require less expensive and less complex water diversion methods.

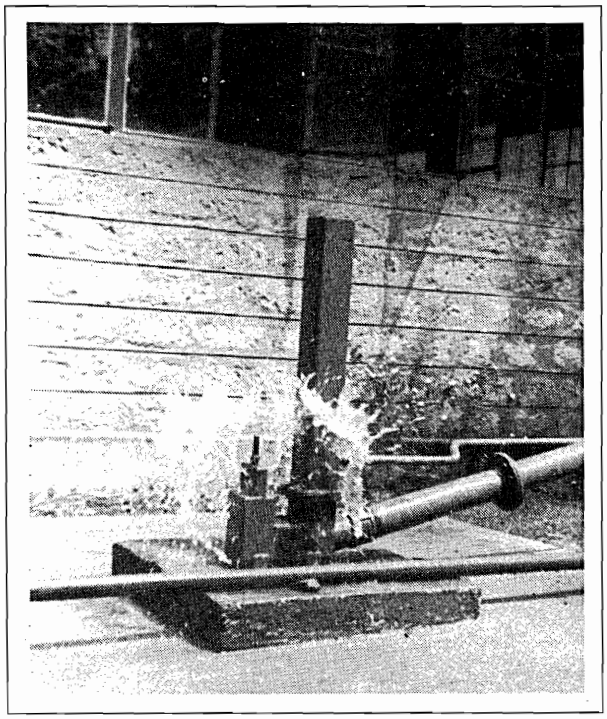
Hydraulic Rams (Hydro-rams).

About two thousand hydraulic rams are working today in streams throughout Kenya. Recognisable by the loud "clack.., clack.. clack ..." sound they make, they use the energy in fast-moving streams to lift water through pipes. Hydro-rams harness the energy in a stream of water moving through an inclined drive pipe to pump a small amount of that water up a considerable height to a storage tank.

Hydraulic rams are the simplest and cheapest hydro-powered water pumping device. Like other hydropowered machines, they work continuously without using fuel. They can provide water for remote farms and communities, allow irrigation and maintain feed water for livestock at a distance from the water source.

Waterwheels

Waterwheels harness the energy of moving water for mechanical work. Moving water in a stream pushes against the blades of the water wheel causing it to turn about its shaft. The turning shaft is used for mechanical work such as grinding, cutting, threshing, sawing, metalworking, water-pumping or air compressing. Watermills have been used by Chinese, Nepalese, Turks, Cretians and Europeans for over a thousand years. During the 1800s, developing European and American industries depended on power produced by waterwheels.



Hydraulic ram, Murang'a College of Technology. Locally made hydro-rams like this one help meet rural water supply needs .

Water wheels are large wheels (often with diameters of 2 metres or more) constructed around a sturdy axle. The edge of the wheel has radially arranged 'paddles' or buckets. The force of moving water against these paddles causes the water wheel to turn about its axis. The turning axle drives machinery (i.e. millstone, saw blade) by means of gears or belts. The first water wheels were made out of wood, with strong iron axles, but they are now made from many different materials. Water is diverted directly to the water wheel from streams by simple channels.

There are two general types of water wheels. The *undershot* water wheel rotates as water passes under the wheel and pushes the paddles from below. Undershot water wheels do not require much head of water, but they are less efficient that other types of water wheels. The *overshot* water wheel rotates as water flows over it. It has buckets (instead of blades) which fill at the *top* of the wheel with water from the diverting channel. The weight of the water in the buckets causes the water wheel to turn. Overshot water wheels need more head than other water wheels (usually at least 3 metres) but give more power than undershot water wheels per the same volume of water.

Turbines

Water turbines are fast-spinning rotors which are most commonly used to generate electricity. As water flows through passages created by turbine blades, it transfers its energy to the revolving turbine (or rotor). Water enters the turbine passages at a high speed, causes the turbine to spin, and leaves the turbine with a minimum of velocity and energy. The spinning turbine axis powers a generator which produces an electrical current. Tana River hydro-electric stations use very large turbines to supply the electric power needed in Kenya's towns and cities. Small turbines can play an important role in electrical supply for remote communities near fast running streams.

There are several types of turbines: The *Pelton (impulse) turbine* uses a jet stream of water to spin a rotor with bucket-shaped blades. It is ideal for generating small to medium amounts of electricity in remote high head situations. *Francis turbines* and *Propeller turbines* spin to generate electricity as water flows across their blades. These turbines are efficient in high flow, low head situations. Francis and propeller turbines are expensive and sophisticated in design, and therefore are most useful on medium to large hydropower projects.

Turbines are much more efficient than water wheels. Since they work at a very high speed, they must be well designed, and this tends to make them expensive. Turbine installations must be well planned, so that the diverted water flows with a uniform speed and pressure. This usually involves the construction of some sort of dam.

Small-scale hyro-electric generating stations supply one third of China's electricity. In Kenya, they have been used successfully in certain areas around Mt. Kenya and Kericho.

Wind Power

As the sun heats the seas, plains and mountains at different rates, inequalities in the temperature of the atmosphere are created. Air masses move to balance these atmospheric temperature differences. These moving masses of air are called *wind.* The kinetic energy contained in wind can be captured and converted into useful forms by *wind machines.* In areas where there is a constant flow of wind, wind machines are excellent sources of mechanical and electrical power.

Wind has been harnessed by man to do work for many centuries. It has been used to propel ships in oceans and lakes. It has been harnessed by windmills to produce mechanical power for pumping water, grinding and threshing grains and cutting wood. It has also been used to generate electrical energy in remote areas.

Kenya is located in a part of the world in which the total available wind energy is comparatively low. However, certain parts of the country have constant winds. These winds are caused by geographical features such as lakes, the ocean and the Rift Valley. Wind mills for pumping water are found along the Indian Ocean, on the shores of Lake Victoria and in the northern parts of the country.

Parts of any wind machine include *rotors, governors* and *tails* which are mounted on a *tower.* The wind pushes against the blades of the rotor, causing it to turn about its axis. As the rotor spins, it turns the axle of a transmission or electrical generator. The tail orients the wind machine so that it faces the wind. The *governor* makes it turn away from the wind (furl) when there is too much wind. Wind machines that produce mechanical energy for pumping water or grinding grain are called *windmills.* Wind machines that generate electric current are called *wind generators.*

A wind machine operates by slowing down the wind and capturing some of its energy in the process. The energy taken from the wind by the blades of the rotor

causes the shaft of the rotor to rotate. The amount of power available from the wind varies with the cube of the wind speed. If the speed of the wind *doubles*, the power avialable from the wind increases *eight* times. A small increase in the speed of wind produces a large increase in the power available. The amount of power that a wind machine can capture depends on the area of its rotor blades. The proper size windmill must be used in each area.

A potential wind power site must be evaluated completely before a wind machine is installed. Wind activity may be very different in two sites that are close to each other, so a careful study of each site is necessary. Information from the nearest meteorological station may help determine if wind machines can be installed successfully.

Windmills

Windmills were first developed in Persia and China many centuries ago for the purposes of grinding grain. Europeans and Asians adopted the windmill technology for such uses as pumping water and sawing wood. European settlers brought windmills to Africa (and America and Australia) to use for pumping water. Because windmills were expensive and imported, they were not used by many Kenyans immediately after independence. However, now that they are manufactured by local companies, and since the price of fuels for pumping engines has risen, windmills are again being used in many parts of the country for pumping water.

Like water wheels, windmills are most often used to produce mechanical power. Windmill rotors have many blades with a large surface area. The large surface area enables the rotor to turn even in relatively light breezes. Windmills turn slowly but produce a high *torque* (turning power) which is necessary for mechanical work. They are well-suited for water pumping because water pumps operate at slow speeds.

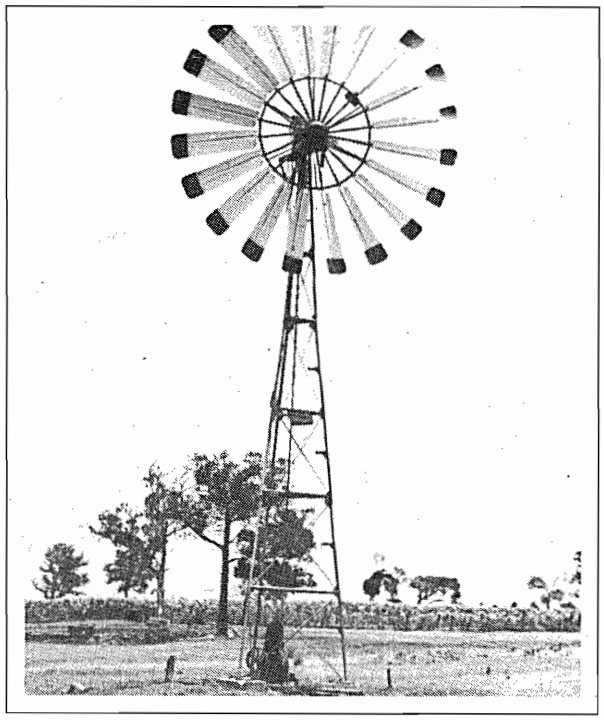
In Kenya, there are over 200 windmills operating in the windy parts of the country. These are used to pump water for cattle ranches, domestic needs and irrigation.

Wind Generators

Wind generators convert wind energy into electricity. This electricity can be used for such purposes as lighting, powering radios, televisions, refrigerators and small machines. Wind generators were used by many Western farmers in the USA to power their lights and radios in the early 1900s. Likewise, in Kenya there are many remote sites in which wind power could be used to generate electricity.

Unlike windmills, wind generators have rotors with fast-spinning blades. Usually, they have two or three blades which are thin like those of an airplane's propellers. They produce a low torque (which means they are not useful for mechanical power), but their high spinning speed is well suited for turning an electric generator. The rotor of a wind generator is attached directly (or by gears or belts) to a generator, and a current is produced when the wind blows.

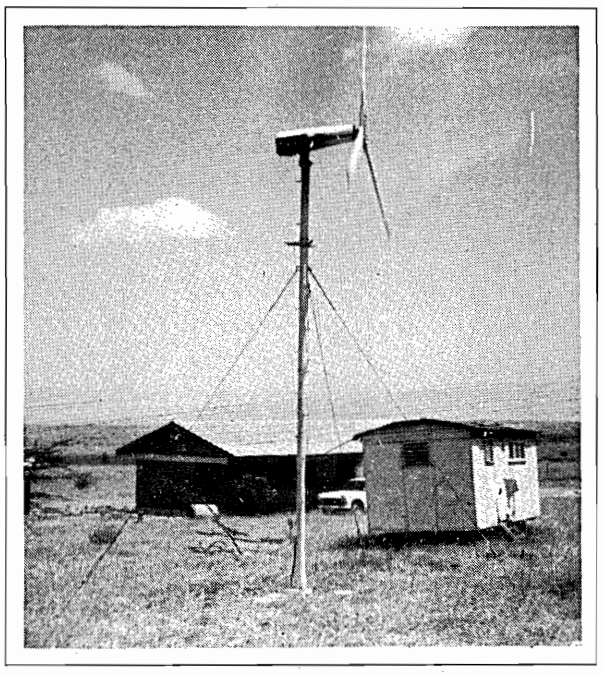
Wind generators are usually smaller than windmills. They are mounted on towers or poles as windmills.



Wind pump, Narumoru. Wind pumps supply water for livestock, domestic need and small scale irrigation.

Wind generators must be carefully designed and constructed because of the high speeds at which they operate.

Because wind does not always blow at a constant rate, the electric energy that wind generators produce has to be stored for calm periods. Therefore, most wind generators are used to charge batteries and the batteries are used to power electrical appliances. Like solar electric systems, wind electric systems need battery storage and control panels to regulate the various system parts. Presently there are fewer than twenty wind generators operating in Kenya.



Wind generators, like this one at Olosseos Health Centre, have a high potential for supplying electricity in areas far from powerlines.

Table 2.1: Practical Renewable Energy (RE) Systems For Rural Schools

LOCATION	ENERGY NEED	RE SOURCE	RE SYSTEM	CHAPTER HEADING
Kitchen	Cooking	Wood biomass	*Conservation:* Institutional stove	3
			Production: Woodlot/Agroforestry	3
		Non-wood biomass	Institutional gasifier	4
		Solar	Solar cooker*	5
Classroom/ Staff houses	Lighting	Solar	Solar electricity	5
		Hydro	Turbine generator	6
		Wind	Wind generator	7
		Non-wood biomass	Biogas lamps	4
Dormitory/ Kitchen	Water Supply	Animate	Handpumps	-
		-	Rain catchment	-
		Hydro	Hydraulic ram/ Turbo pump	6
		Wind	Wind pump	7
		Solar	Solar electric pump	5
Dormitory/ Kitchen	Hot water	Solar	Solar water heater	5
		Wood biomass	Institutional stove	3
		Non-wood biomass	Institutional geysers	4
Shamba	Fertiliser	Wood biomass	Agroforestry	3
		Non-wood biomass	Biogas effluent	4
Laboratory	Gas	Non-wood biomass	Biogas burner	4

* Experimental or unproven renewable energy system

Trees For Energy 3

Increasing Kenya's Woodfuel Supply

This section describes the present woodfuel situation in Kenya. First, the sources of and demands for woodfuel in the country are described. Next, the woodfuel *deficit* (the fact that demand for wood is greater than the sustainable supply) is explained. Finally, efforts by the government, private industry, and the public to produce more fuelwood are outlined. The government, with assistance from NGOs (non-governmental organisations), is encouraging tree planting by individuals and communities because it cannot hope to supply the whole country's woodfuel demands with its limited land and financial resources.

The Fuelwood Supply

In terms of agricultural production, Kenya can be divided into three climatic zones, the *high potential areas*, the *medium potential areas* and the *arid and semi-arid areas*. The type of woodfuel used and its availability depend on which zone one lives in, whether high potential or semi-arid, as well as rural or urban.

High and Medium Potential Areas

Concentrated mostly in the highlands of Central, Eastern, Nyanza, Rift Valley and Western Provinces, high-potential land makes up about 15% of Kenya's land mass. Medium-potential land, which is found in the above mentioned provinces as well as along the coast, makes up another 5% of the country's land. More than a quarter of the country's wood supplies are located in these two zones (although most of these resources are in protected forests).

Deforestation in Kenya is primarily due to land clearing for agriculture. Because most of Kenya's food and export crops are produced in the high and medium potential zones, land clearing has greatly reduced the number of trees available there. As most of the population is located in these areas, woodfuel demand is very high. Consequently, wood stocks are rapidly being depleted in these zones, and woodfuel shortages are already a serious problem in many local areas.

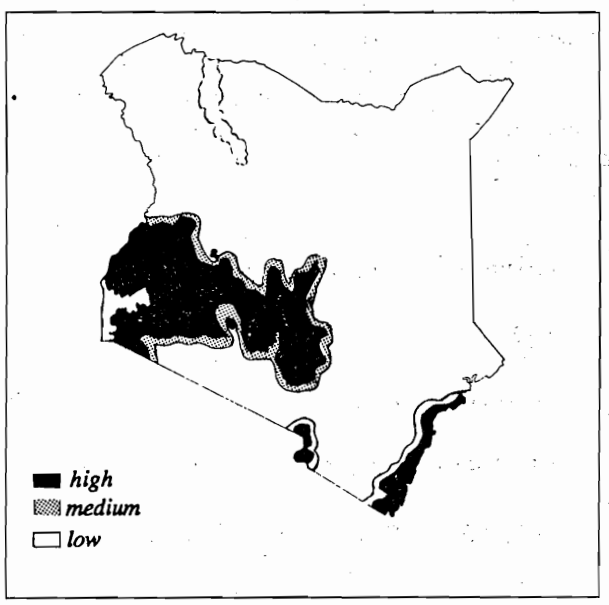
Arid and Semi-Arid Lands (ASAL)

About 80% of Kenya's land is arid or semi-arid. Although less densely forested than the highlands, the huge ASAL areas contain more than 70% of the country's forest resources. People in semi-arid zones do not usually face wood shortages. ASAL lands are sparsely populated by nomadic pastoral people who, in most cases, do not cut down trees for firewood, but instead gather fallen wood.

However, most of Kenya's charcoal is produced from trees in ASAL lands for use in urban areas such as Nairobi, Mombasa and Kisumu, causing serious deforestation in many semi-arid areas. With the rising urban population this situation can be expected to worsen.

Firewood

Firewood (also called *fuelwood*) is not cheaply transportable, and it therefore tends to stay in the area where it is cut. Farmers regularly cut branches from



High, medium and low (ASAL) potential areas

trees or gather dead wood on their own land or on a neighbour's land, and this accounts for the fact that more than 40% of Kenya's fuelwood supply comes from agricultural land. Fuelwood is also collected from undeveloped bush or rangeland by women and children who may have to walk many miles in search of it. Wood dealers collect fuelwood in undeveloped rangeland in order to sell it in areas with serious wood shortages, transporting it short distances (up to 80 km) by pick-up or lorry.

Large government and private fuelwood plantations mainly serve industrial requirements such as the tea industry. They supply less than 10% of the country's firewood requirements and have little impact on rural individuals' energy needs.

Charcoal

Charcoal is a more concentrated fuel than wood and is thus more economical to transport. Kenya's charcoal is made from trees in semi-arid rangeland, bushland and cleared agricultural land. Most of the charcoal used in Kenya is carried by road to the urban areas where it is used. However, some Forest Department plantations such as Ngong and Karura Forests have contributed to the charcoal supply.

Charcoal may be transported up to 300 km to city markets where it is sold. Ninety percent of Nairobi's charcoal supply, for example, comes from Eastern and Rift Valley Provinces. Kisumu's charcoal comes from Western and Rift Valley Provinces. Much of Mombasa's charcoal comes from the North Eastern Province.

The Fuelwood Demand

In 1980, the total Kenyan demand for wood was about 20.82 million tonnes, of which 94% (19.64 million tonnes) was used as woodfuel (charcoal or firewood). Woodfuels are used by rural households, urban households and industry as described below:

Rural Households

Making up about 85% of the population, rural households use about 60% of Kenya's woodfuel supplies for cooking, space heating and warming water. They are the largest consumers of firewood (using 72% of the total demand). A significant amount of them use charcoal as well.

Urban Households

Urban households are the largest consumers of charcoal, demanding half of the charcoal produced in Kenya for their heating and cooking needs. Very few urban dwellers cook with wood, mostly because it is not available in towns. Because charcoal production is energy intensive, city dwellers have a higher energy demand than rural households and therefore place a great burden on Kenya's forests.

Industry

Kenya's industrial sector consumes about 20% of the country's woodfuels in the form of both wood and charcoal. The industrial sector can be divided into 3 different categories: large, rural informal and urban informal industries.

Rural informal industries use 11% of the overall fuelwood demand. They also use much charcoal. These industries include brewing, butcheries, baking, hotels, small brick burning, blacksmiths, as well as fish, tobacco and agricultural drying. The brewing industry, in particular, uses large amounts of woodfuel.

Large industries consume 6% of the total fuelwood demand. These industries include centralised tea, baking, wood processing, tobacco, sugar, brick burning and cement production companies. Tea, wood processing and baking, have especially large demands for woodfuel. Some of these industries use wood but do not rely on it exclusively as a fuel. They may use non-wood fuels such as petroleum, electricity and even bagasse. Sugar factories generally burn bagasse (sugar cane waste) as a boiler fuel for heat and electrical generation.

Urban informal industries are smaller consumers, requiring only 2% of the total fuelwood demand. These industries include workshops, garages and restaurants. Of these the most significant energy users are restaurants which consume mostly charcoal for their cooking tasks.

Commercial/Institutional include schools, hospitals, hotels, prisons and office buildings. They account for only about 1% of the wood energy used in Kenya, consuming both fuelwood and charcoal.

Table 3.1: Climatic Zones, Population and Wood Resources (%)

Zone	% of Area (Hec.)	% of Pop.	% Wood Stocks
HIGH POTENTIAL	15% (8516000)	81%	20-25%
MEDIUM POTENTIAL	5% (2789000)	9%	4-5%
ARID/SEMI-ARID	80% (4561000)	9%	70-75%

Source: Beijer Institute, 1980

Table 3.2: Wood Energy Demand by Sector, 1980
(%/ Million Tonnes Roundwood Equivalent)

SECTOR	Fuelwood %	Fuelwood RE	Charcoal %	Charcoal RE	Total Wood Demand %	Total Wood Demand RE
Rural HH	72	9.24	37	2.52	60	11.76
Urban HH	1	0.13	50	3.41	18	3.54
Industry	26	3.34	12	0.82	21	4.16
Institutional	1	0.13	1	0.06	1	0.19
TOTAL	100%	12.84	100%	6.82	100%	19.65

Source: Beijer Institute, 1980

The Fuelwood Deficit

Wood is only a renewable resource if the annual supply of wood products can keep up with the demand for them. This is not presently the case in Kenya because trees are being cut down *much faster* than they can replace themselves.

Standing Stock and Sustainable Yields

The amount of trees on an ideal farm that supplies its own wood products should always remain constant. Successful management of trees for wood supplies, even on a small farm, requires a knowledge of the terms *standing stock* and *sustainable yields.*

Suppose for example, that a farmer has a number of mature trees on his *shamba.* These trees, called the *standing stock,* represent all of the wood reserves he has. The farmer cannot cut down all of the trees at once and expect to have continuous wood product supplies. He would have no source of poles, timber or firewood until several years later when replanted trees matured. The farmer must thus harvest wood by cutting branches and trees only at a rate that is *sustainable.* The *annual yield* is the increase in growth of the standing stock in one year.

Suppose that on a farm the total *standing stock* has not been reduced by the farmer's tree product harvesting. This means that the trees are growing at a rate that is fast enough to meet the farm's needs. The farmer coppices or prunes trees for fuelwood, poles and timber, but they grow back and he replants others to replace those cut down. In this case, the farmer is being supplied by *sustainable yields* of his *shamba's* wood product.

However, suppose that on another farm the standing stock has been reduced by half after two years. In this case, the farmer's family's *demand* for wood products is greater than the *sustainable yields* of his land. Because he has been cutting down standing stock, the number of trees on his land is rapidly decreasing. This *shamba* has a *wood deficit,* meaning that the demand for wood is greater than the supply.

Farmers should only harvest trees and branches at a sustainable rate.

There are two ways that any farmer can solve his land's wood deficit. First, he can reduce his woodfuel consumption by using fuelwood conservation techniques (as described in the second part of this chapter) and by buying poles and timber from the market. Secondly, he can *plant more trees.*

The Situation in Kenya

Kenya now faces a serious woodfuel deficit. People cut down more and more trees as they clear agricultural land and search for fuelwood. Increasing numbers of people in rural areas require increasing amounts of woodfuel, poles and timber, and increasing numbers of people in urban areas demand more charcoal. Growing industries, services and institutions consume greater amounts of woodfuel. As of 1980, Kenyans were cutting trees at a rate that is *43% higher than sustainable yields.* The country's standing stock of trees is being rapidly reduced. The situation, as of 1987, is becoming worse.

The problem is particularly serious in the most densely populated parts of the country. Valuable natural forests such as Mau, Kakamega and Mount Kenya have already been seriously damaged by charcoal-makers, wood cutters and squatters clearing land for agriculture. There are woodfuel shortages in Central, Nairobi, Nyanza and Western Provinces. Once favourite fuelwood tree species such as *Olea africana* are now scarce.

Example:

The Wood Deficit in Western Province, 1980

Western Province is an area with a serious woodfuel shortage. Yearly demand for wood includes the following:

Local fuelwood demand	1,980,000 tonnes/year
Charcoal exports to other provinces	300,000 tonnes/year
Industrial feedstock for sawmills and papermills	40,000 tonnes/year
TOTAL DEMAND FOR WOOD	2,320,000 tonnes/year

The total demand for woodfuels of over *2 million tonnes* per year is much higher than the sustainable yields in Western Province. The *annual sustainable wood yields* are only about 310,000 tonnes/year in Western Kenya. This means that standing stock is being reduced rapidly:

Total wood demand	2,320,000 tonnes/year
minus Total sustainable yields	310,000 tonnes/year
WOOD DEFICIT	2,010,000 tonnes/year

The estimated total wood stock in Western Province (including gazetted forests) was about 13,660,000 tonnes (in 1980). Thus, if stock is being cut at a rate of over 2 million tonnes per year, it is clear that forests are being rapidly depleted. If trees were not being planted in great numbers, Western Province would run out of trees in less than a decade.

Source: Beijer Institute, 1980

The fuelwood crisis is already upon us. Action is being taken by the government and private industry, as well as *wananchi.* Large plantations are being planned and planted to meet urban demands. Fuelwood demands of rural people will, however, rely mostly on the rural people themselves planting trees. The following sections describe strategies that large and small tree-planting organisations are using to fight the fuelwood crisis.

Government and Private Sector Forestry Approaches

Most of the government's forests and plantation management schemes produce pulp wood for making paper, sawn wood for building and transmissions poles for power and telephone lines. However, a small number of plantations have been planted near large urban areas to supply woodfuel needs. The government's plantations supply about 10% of the nation's woodfuel requirements, most of which is sold to industry. The government has 4 general forest management regimes:

Natural Forests

Natural forests are protected because they are environmentally sensitive areas which are valuable as water catchment areas and wildlife reserves. In some forests, selective felling of certain species for commercial purposes is allowed. These cuttings are carefully controlled by the government.

Cutting trees inside gazetted forests without a special licence is illegal, and thus natural forests produce no significant amount of woodfuel, although people are allowed to collect dead wood from them. Examples of protected natural forests are the Mount Kenya, Kakamega, Aberdares and Marsabit Forests.

Industrial Saw-wood Plantations

Many saw-wood plantations produce timber for carpentry and building applications. However, these plantations also supplement woodfuel production. Significant amounts of wood (10-30% of the total biomass) are available from the plantations as logging residues and thinnings, and these are collected for fuel use by people. About 50% of the log at the sawmill site is sawn waste which can be used as fuel.

However, industrial plantations are often located far from populated areas where there is a demand for fuelwood. Consequently, wood residues often go to waste. In Uganda, charcoal-makers use portable kilns to make charcoal from wood in plantations. Such an approach for making wood residues marketable has a good potential in Kenya.

Fuel/Pole Plantations

About 10,000 large and small government plantations in Kenya grow eucalyptus and casuarina in 7-10 year rotations for production of poles and fuelwood. Most of these plantations' primary products are transmission poles for telephone and power lines. After harvesting, Kenya Posts and Telecommunications Corporation (KP&TC) and Kenya Power & Lighting Company (KP&LC) remove poles and the large amount of remaining wood is then sold to dealers. Many fuelwood plantations are located in Kiambu, Nyeri, Uasin Gishu and Kakamega.

Peri-Urban Woodfuel Plantations

Peri-urban woodfuel plantations grow trees exclusively for the use of people and industries in urban areas. The wood is usually carbonised before being sold in the city as charcoal. Ngong and Karura Forests outside Nairobi are examples of peri-urban plantations.

Private Plantations

Some large local companies have planted their own fuelwood plantations or encouraged member farmers to do so. These fuelwood plantations now supply significant amounts of fuel energy demanded by the tobacco and tea curing industry. Private plantations have the potential of supplying 100% of Kenya's industrial woodfuel needs.

East African Tannin Extracting Co. (EATEC)

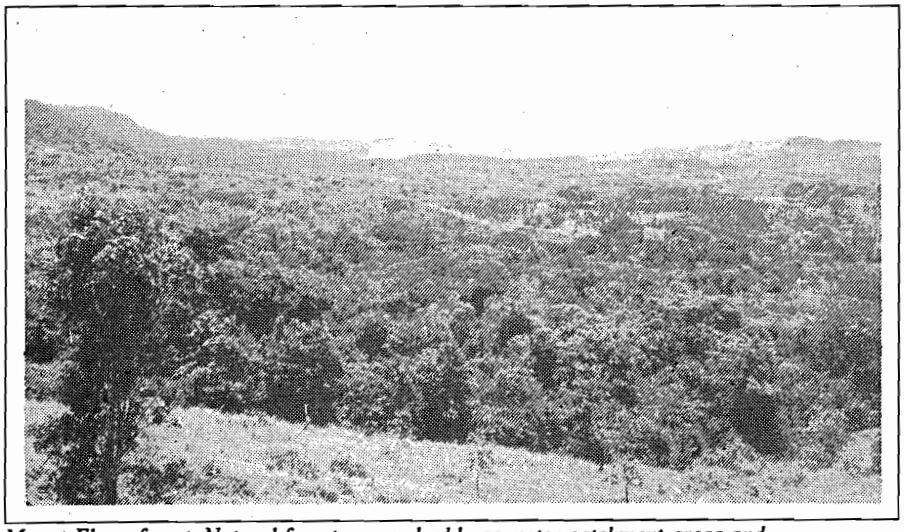
EATEC's main business is extracting tannin from the bark of black wattle for use in the leather industry. The company has therefore planted thousands of hectares of black wattle to supply bark for tannin. As of 1975, plantations near Eldoret yielded a sustainable supply of about 223,000 m^3 of black wattle per year.

EATEC sells much of the debarked black wattle as woodfuel. Twelve permanent brick kilns are used to produce a high quality charcoal from the excess wood. The charcoal is sold to local dealers.

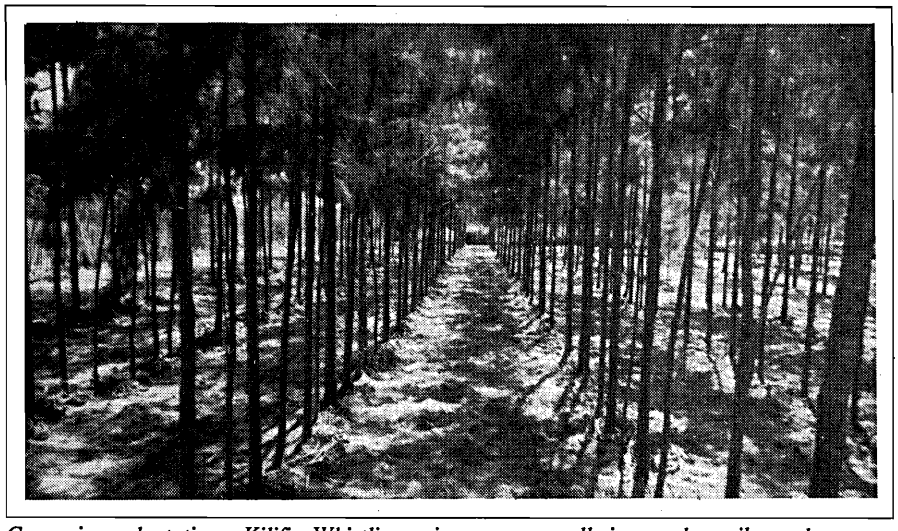
There are many small woodfuel plantations in Uasin Gishu District which sell bark to EATEC and use the remaining wood locally.

Thika Wattle Factory

Another wattle factory is located near Thika and many small farmers grow wattle to meet the requirements of this factory. After felling and debarking, the wood is sold as poles, as fuelwood or is converted to charcoal.



Mount Elgon forest. Natural forests are valuable as water catchment areas and wildlife reserves.



Casuarina plantation, Kilifi. Whistling pines grow well in sandy soils and can also be use in various agroforestry applications.

British American Tobacco (BAT)

The tobacco curing process requires a lot of fuelwood and in the past the industry was responsible for much deforestation. However, following the government's policy, BAT now requires all of its tobacco farmers to plant fuelwood trees to replace those cut. BAT is now almost completely self-sufficient in fuelwood.

BAT supports its own nurseries and out-planting operations in Meru, Machakos and Kisii. Farmers are supplied with fast-growing *Markhamia, Eucalyptus, Cassia siamea* and *Grevillea robusta* seedlings and are shown how to care for them. Farmers cannot be registered as BAT tobacco growers unless they can show that they plant 1,000 trees per year for every hectare of tobacco planted.

Kenya Tea Development Authority (KTDA)

Using almost 300,000 tonnes of fuelwood per year in tea processing, the tea industry is among the largest industrial consumers of fuelwood. Some tea estates have their own woodfuel plantations (e.g. Kericho), but these plantations are not big enough to produce a sustainable supply for the entire tea industry.

Presently KTDA is dependent on the Forest Department plantations for a large part of its woodfuel and it receives first priority with the Forest Department plantations. Like BAT, KTDA now encourages tea farmers to plant woodfuel plantations.

Social Forestry

The last section discussed some of Kenya's successful large-scale tree planting efforts. Although plantations provide 95% of the industrial timber, pole and wood pulp (paper) demand, they yield only a fraction of the country's woodfuel needs. The government does not have the financial nor manpower resources to plant trees for all of Kenya's woodfuel demands. It therefore encourages all people to meet tree product needs by planting trees on their own land. Tree-planting is a particularly important activity in those high potential areas where woodfuel shortages are already felt. *Social forestry* deals with the planting of trees on a small-to-medium scale by individuals or communities.

Treeplanting, however, is not a simple task. There is already competition between cash crops and food crops on high potential land, limiting the amount of trees that small plot holders can plant. Some trees reduce crop production by shading or competing for water. Other trees grow too slowly to produce sustainable fuelwood yields. Thus, the choice of tree species is a critical aspect of tree planting. In addition, *shambas* require that trees be planted according to a carefully planned system. The location, arrangement and type of trees planted will all affect a farm's output.

Elements of Social Forestry

Education and motivation. For individual or community tree planting efforts to be successful, people must be *motivated* to plant trees. People will take tree planting more seriously when they recognise that trees, because they provide beneficial products and services, can save, and actually generate money. Thus, in order to motivate people, educational campaigns which teach the benefits of trees, the potential for trees to increase farm productivity, and even to raise cash, are essential. Also, people should understand that tree planting projects take a lot of time and effort, and are long-term commitments. People involved should judge the benefits gained versus the efforts required when determining whether or not to pursue particular tree planting activities. Education is the cornerstone of social forestry, and a good understanding of the costs and benefits involved will ensure continued enthusiasm.

Tree species selection. Once an individual or group is committed to pursuing a tree planting project, the next step is *tree species selection.* The needs of a community (or individual) will motivate them to plant particular types of trees. For example, if the main tree product need is woodfuel, then mango or paw-paw seedlings will not be very useful. It is best to select a range of tree species that can supply a wide variety of needs (species that can grow well in the particular climate-type, of course). The book by Wayne Teel, *A Pocket Directory of Trees and Seeds in Kenya**, is an excellent source of information on appropriate species for any area in Kenya.

Finding seeds. Once the species are chosen, seeds of the chosen trees must be located. If the trees are indigenous or locally grown, then the best way to get seeds is to collect them from healthy local mother trees

**A Pocket Directory of Trees and Seeds in Kenya*, Teel, Wayne. Kenya Energy Non-Governmental Organizations, Nairobi 1984.

during the proper season. Seeds from healthy local trees are usually better than seeds from the same species in another climatic zone. Otherwise, seeds are available from several local sources:

- District Forest Officer
- The nearest Ministry of Energy and Regional Development (MOERD) Agroforestry Centre. (See appendix)
- Kenya Energy Non-Governmental Organisations (KENGO). (See appendix)

Starting Nurseries. The next step is growing trees from the seeds. This is accomplished in nurseries. Nurseries provide a protected place for young seedlings to grow strong before out-planting so that they have a better chance of surviving.

Nurseries are central places for preparing and sowing tree seeds. They protect seedlings from damage by livestock or drought. They also give seedlings a head start on growth before the rainy season out-planting.

The Forest Department and non-governmental community organisations operate many large nurseries that may produce 5,000 or more seedlings each season. However, an individual can easily grow twenty to one hundred or more seedlings for his own needs in a nursery on his farm. The size of any nursery depends on the surrounding area's need for trees as well as the local motivation to care for them.

Nurseries should always be set up near permanent sources of water. They should be built on flat, well drained sites that are accessible to local people and the transport network. Nurseries should, if possible, be located near a source of rich, humus-containing soil.

Important parts of any nursery include *germination beds* (raised or sunken) where seeds are planted and germinated, *seedling beds* (raised or sunken) where pricked out seedlings are planted, *shading* to prevent damage to young trees from the sun, and *fencing* to keep livestock and people out of the seedbeds. You can find out more about nurseries by visiting the one nearest your home or school.

Direct Sowing. Certain tree species can be sown in the fields with agricultural crops during planting. Such directly sown species will need special care and attention but are hardy enough to be grown successfully on *shambas* from seed.

Outplanting and Management. The final steps in social forestry planting programmes are the outplanting and subsequent management of the tree seedlings. Selecting proper planting sites for young trees and protecting them is crucial for their survival. Unprotected seedlings may be eaten by goats. Unwatered young trees in dry areas often do not survive their first year. Trees planted "by chance" and left uncared for thus do not have a high survival rate. However, trees planted according to a system which quickly makes use of benefits and services provided by the tree have good survival rates.

Large nurseries may produce 5,000 or more seedlings each season, but individuals can easily build much smaller nurseries for their own needs.

Agroforestry

Agroforestry is a collective name for a variety of tropical land use systems involving the mixture of tree planting and agriculture. These systems enable farmers to produce agricultural crops, tree products and livestock on the same unit of land. Trees, shrubs or palms are purposely planted in association with farm crops. When properly planned and managed, agroforestry practices can increase a farm's overall productivity. Benefits to the farm from wood products and tree services are maximised without any environmental damage.

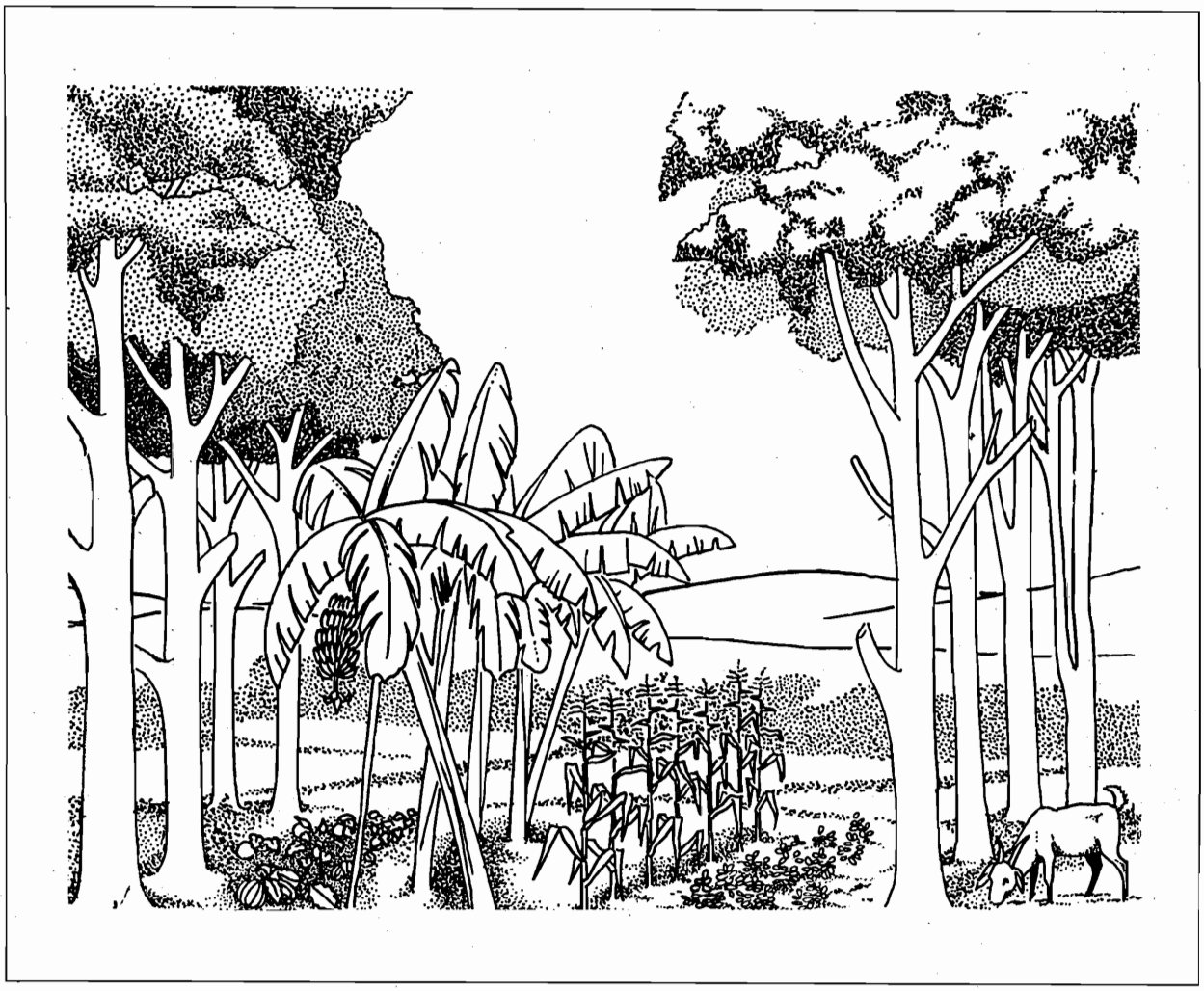
Types of Agroforestry

There are three major types of agroforestry:

Agri-silviculture involves the inter-cropping of crops and trees in some sort of spatial arrangement and/or seasonal rotation. An example of agri-silviculture is the planting of nitrogen-fixing shrubs in lines between crops (such as maize or beans) to enrich the soil while providing woodfuel and wood products at at the same time.

Silvopastoralism combines tree-farming and animal production in land-use management. These systems may provide shade and fodder for livestock while wastes from livestock are in turn re-cycled into the soil to nourish the trees and agricultural crops.

Agro-silvopastoralism integrates crop,



Agroforestry systems enable farmers to produce agricultural crops, tree products and livestock on the same unit of land

tree and animal production on the same unit of land. An example of this type of land management is a Central Highlands farm where trees are planted among rows of crops and on which cattle are kept in zero-grazing enclosures.

Benefits of Agroforestry

The effectiveness of all forms of agroforestry is based on the use of trees. The absence of trees from most landscapes results in erosion, decreased water retention, decreased agricultural production, and subsequent lowered human welfare conditions. Trees and shrubs, particularly under agroforestry systems, provide the following benefits:

- A sustainable source of firewood and/or charcoal,
- Other tree products (fruits, poles, timber, fodder, etc.) which can be sold or used,
- Protection to the soil from sun, wind and rain increasing its water retention ability and decreasing erosion, and
- Enrichment of the soil by addition of organic material and minerals from leaf litter and nitrogen fixation.

Not all tree species are good for agroforestry. As a general guide, an agroforestry species should have one or more of the following characteristics:

- Fast-growing
- Nitrogen-fixing
- Deep-rooted
- Palatable and nutritious leaves for fodder
- Wood product and by-product production (e.g. fruits, timber, dyes, medicines, poles and honey).

Why Agroforestry?

In Kenya, deforestation has led to woodfuel shortages and environmental degradation. This problem is getting worse, and agroforestry has potential to ease it quickly. Already, more than 40% of Kenya's woodfuel supplies come from agricultural land. A large portion of the rural population get woodfuels from trees on their own land or by arrangement with neighbouring *shambas*. Even now, Kenyan women prefer to cook with the firewood produced by rapid growing agroforestry species such as *Grevillea robusta, Leucaena leucocephala* and *Sesbania sesban*. Increased use of agroforestry methods will go a long way towards solving the fuelwood crisis.

Agroforestry allows people to produce their own tree products, which they can sell or use at home.

Trees play an important role during drought times. Even during droughts, and other natural disasters when agricultural crops have failed, trees continue to grow producing food for people (e.g. fruits and nuts), food for livestock (fodder), and such saleable products as timber, charcoal and honey.

Because agroforestry systems protect, conserve and enrich the soil, they improve agricultural productivity despite the occupation of about 10% of the land with trees. Unlike many agricultural systems which clear the land, encouraging deforestation, agroforestry combines farming and afforestation. All of the agricultural land in Kenya can be viewed as potential agroforestry land.

Traditional and Established Agroforestry Systems

Agroforestry is not a new farming practice in Kenya, as the following three examples will show. The systems discussed could, however, be further improved by introduction of more intensive methods and more productive trees.

Silvopastoralism at the Coast.

Coconut plantations produce a very important food and cash crop for coastal farmers. Allowing livestock to graze in the plantations increases coconut production and makes optimum use of the land.

Coconut palms provide windbreaks that help stimulate the growth of grass as well as shade which improves livestock grazing conditions. Livestock, meanwhile help control the growth of weeds on the ground while their wastes re-cycle valuable nutrients and organic matter into the sandy soil. This type of silvopastoralism is also used in cashew nut plantations.

Agro-Silvopastoralism in the Highlands.

Farmers in the Central Highlands have long used integrated farming systems involving the growth of indigenous trees such as *Cordia abyssinica* and *Markhamia*. *Grevillea robusta*, an exotic tree, is also now intercropped with crops on farm land and in pasture lands.

Markhamia and *Cordia* both produce poles, timber and woodfuel products. Leaf litter from the trees adds humus to the soil, and the trees perform an important water conservation role as well. *Grevillea*, a fast-growing species, is prized for the firewood that can regularly be pruned from it, as well as the poles and leaf litter that it produces.

Lake Basin Agro-Silvopastoralism: *Okang*

"*Okang*", a Luo word meaning "new land", describes a land management system used in Western Kenya. The "*okang*" system leaves exhausted crop land fallow for two or more years, during which time animals are allowed to graze on it and trees are left to grow.

Sesbania sesban, *Combretum molle*, *Markhamia platycalyx* and *Cassia siamea* (an exotic), are allowed to grow naturally on the fallow land. Fast growing *Sesbania* improves the soil by fixing nitrogen and stabilising it, besides providing fodder, woodfuel and building poles. *Combretum*, especially prized for the tool handles made from its wood, also provides mulch, timber and woodfuel. *Markhamia* is used for poles and woodfuel. *Cassia siamea* leaves are good mulch, while its wood is used as building poles and woodfuel.

During the time that the land is left fallow, it is used for grazing. Goats, sheep and cattle add their wastes to the soil and increase its organic matter content. Three or four years later, the soil-enriching activities of the trees (and grazing animals) have greatly improved the agricultural value of the land. The land is then re-cleared for planting and trees are either harvested or left standing.

Agroforestry Systems

The agroforestry system chosen for a farm depends on the size of the plot, the type of crops being planted, the number and type of animals being raised, and the wants and needs of the farmer and his family. Several general ways of applying agroforestry methods are described below (including woodlots which, strictly speaking, do not use agroforestry methods).

Intensive Hedgerow Intercropping (Alley Cropping)

Hedgerow cropping is a farming system by which rows of trees or shrubs are planted on contours between rows of crops for soil and crop improvement. Leguminous trees both conserve and improve the soil. In a typical hedgerow system, fast-growing nitrogen-fixing shrubs are grown in closely spaced rows with crops such as maize or beans. Trees are coppiced (cut back to about half a metre) at the beginning of each cropping season so that they do not compete for sunlight, water or nutrients during the agricultural season. The trees are cut back again during any subsequent weedings but allowed to grow between the crop seasons. This system provides soil improvement benefits very similar to those of leaving the land fallow for two or three years, but without the lost cropping seasons.

Intensive alley cropping provides regular supplies of fodder, fuelwood and poles. However, in these systems, the soil improvement and water conservation services performed by the trees are at least as important as the tree products. The presence of the tree benefits the crop while the protection and attention given to crops helps ensure the survival of the tree.

How Crops Benefit Trees

Tree seedlings planted with crops have high survival and growth rates because they receive the same attention given to crops:

- They are fenced and/or watched and protected from grazing livestock and wild animals.
- They are weeded at the same time as crops and thus have less competition from weeds.
- They can make use of applied fertilisers leached below the level of crop roots.

How Trees Benefit Crops

Adding nutrients to the soil. The presence of trees on agricultural land increases the potency of the soil in several ways:

Nitrogen Fixation. Micro-organisms (bacteria) in root nodules of leguminous shrubs fix atmospheric nitrogen (N_2) into a form that crops can use.

Green Leaf Manure (GLM). Leaf litter from trees provides major nutrients, micro-nutrients, and organic matter for the soil. In a process called *nutrient pumping*, deep roots of trees carry valuable minerals from deep below the soil surface to the leaves. When the leaves fall from the tree they decompose and add the minerals to the top soil.

Root Decomposition. Regular coppicing causes roots of trees to die back and decompose adding organic matter to the soil. Usually, trees are coppiced around planting time and the root dieback reduces competition for water and nutrients.

Soil Organisms. The micro- and macro-organisms (bacteria, protozoa, earthworms, insects, etc.) associated with higher moisture content improve the soil by aerating it and adding organic wastes.

Conserving water. Trees increase soil water retention:

Shade. Between cropping seasons, tree crowns minimise direct radiation of exposed soil and thus lower evaporation losses.

Wind breaks. Also between cropping seasons, trees act as wind breaks and reduce the increased rates of evaporation associated with high winds.

Organic matter. Like a sponge, organic matter deposited in the soil by trees increases the soil's ability to absorb and retain water.

Conserving soil. Trees reduce the rate of soil erosion in several ways:

Roots. The tree roots hold the soil together. This is especially valuable when trees are planted along the contours of a hill side.

Leaf litter on the soil surface (and the *tree canopy*) lessen the force with which raindrops strike the soil. This allows larger amounts of water to seep into the ground and reduces the amount of soil carried away by runoff.

Wind breaks. The wind break provided by the trees lessens the wind across the top soil, lowering the amount of soil blown away.

Reducing weeds. Shade provided by trees lowers weed growth between and during cropping seasons by reducing competition.

Hedgerow intercropping with Calliandra calothyrsus and beans in Central province.

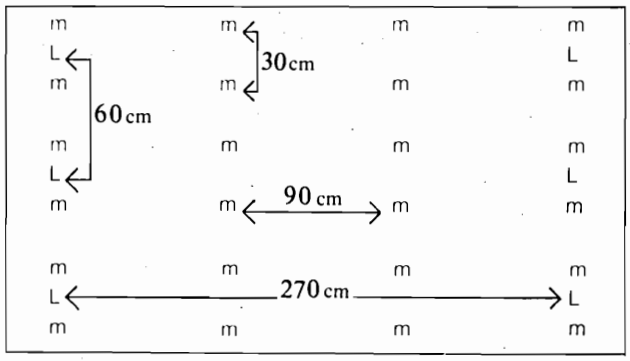
Example: Intensive Hedgerow Intercropping with *Leucaena*

Establishing *Leucaena leucocephala* with Crops

Choosing Sites. *Leucaena* can grow in most areas in Kenya, however, its best growth rate is in warm, high rainfall areas such as the Coast and the Lake Basin. *Leucaena* is also drought tolerant, and therefore suitable for semi-arid areas. At high elevations (1500 metres and above), the growth rate is limited by temperature, and other species (such as *Calliandra calothyrsus*) are more suitable. Leucaena grows in all soil types except very acid soils (pH 5.2 or less, such as those found in swampy areas), and can even tolerate very shallow or rocky soils.

How to Plant. *Leucaena* is best established through seedlings, but can also be directly sown in the field. If directly sown, seeds should be pretreated by soaking them in hot water (80°C) for 3 minutes. In the field, the seeds should be planted directly within the crop rows as illustrated.

For maximum productivity, close spacing of the trees is best. The suggested arrangement is 2 to 3 metres between rows, and



(m = a maize plant, L = a leucaena plant)

0.25 to 0.5 metres between trees within the row. However, the exact spacing depends on: 1) the principle crop grown in the *shamba*, 2) MOALD's recommended spacing for this crop, and 3) whether a tractor is used in cultivation. For example, if the dominant crop is maize, the trees are best planted in every second or third maize row, but if a tractor is used in cultivation, they should be planted every fourth row to leave room for the tractor to pass. Within each row planted with *leucaena*, the trees should be planted either between each maize plant or between every other maize plant.

The example given above is for planting with maize at the coast (where the recommended maize planting distance is 90 x 30cm), where the trees are planted in every third row, and are planted between every other maize plant within the row. Once planted, the trees will benefit from protection, weeding, and fertilizer application to the crop, and will require no other special care. Any trees that die, however, should be replaced.

Establishment Phase. The establishment phase is the period between when the trees are first planted and when the trees are first cut. The trees should not be cut until they reach 3 to 4 metres in height (this can take as little as 10 months at the coast and as much as 2 or 3 years in highland areas). Despite the risk of crop decline in the last planting season in this establishment phase, the long period of growth will allow the *leucaena* to establish a deep root system and reach a large enough size so that it will coppice vigorously.

NOTE: If the trees begin producing pods, it is best to remove them before they ripen. Green seed pods can be used as a very high protein fodder, or as a green mulch. If the seeds do fall from the tree and germinate, they should be removed during weeding.

Management of *Leucaena*

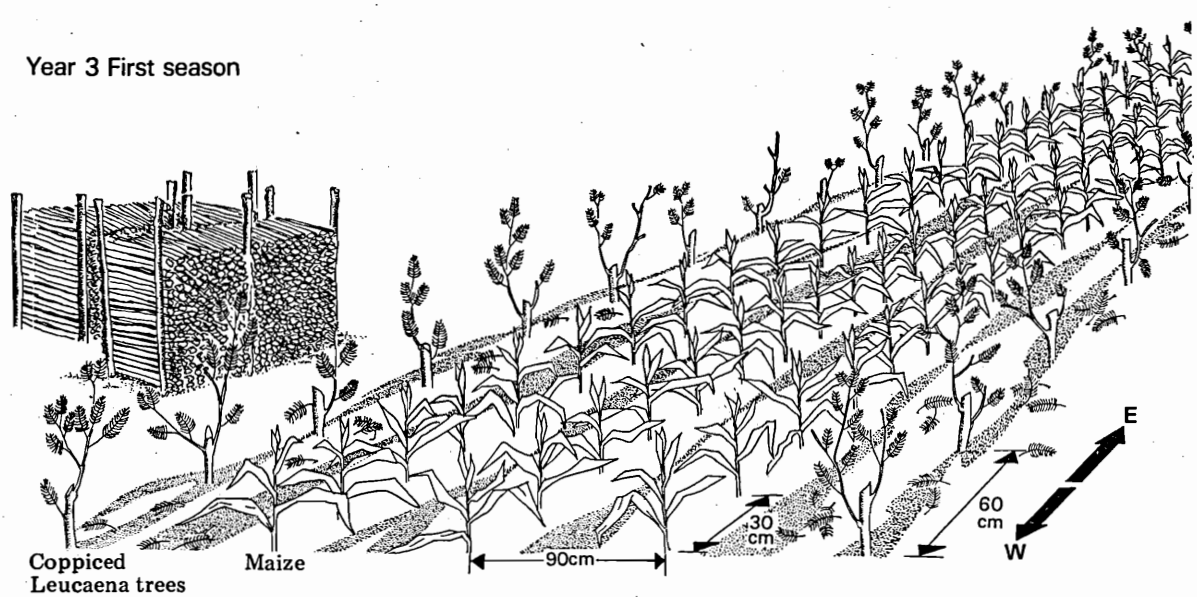
Once the trees are 3 to 4 metres tall, the seasonal management system described below can be initiated.

Coppicing Season. One week before land preparation begins, the trees should be cut 0.5 metres above the ground. The day before first ploughing (six days after cutting), the wood should be harvested and removed from the field. The dry leaves will be incorporated into the soil during ploughing. Planted crop rows are henceforth staggered with the tree rows as illustrated.

During the growing season, every time the crop is weeded, the trees' young green shoots should be cut again. The shoots can either be used as fodder or, for higher crop yields, can be incorporated in the soil by cutting the shoots a day before weeding. After the last weeding, allow the trees to grow through the rest of the planting season as they will not interfere with the maturing crop. This management scheme is practiced during both the long and short rain cropping seasons.

Between Cropping Seasons. During the dry season the trees should be allowed to grow unhindered as they produce large amounts of fuelwood and fodder. As well, they will provide a vegetative cover to the soil protecting it until the next planting season (as discussed in the previous section).

Established Leucaena/Maize Alley-cropping System



(Source: *Leucaena for Kenya*, Leaflet, Kenya Renewable Energy Development Project, 1986)

Table 3.3: Useful Hedgerow Intercropping Species

SPECIES	SUITABLE AREAS		
	COAST	ASAL	HIGHLANDS
Leucaena leucocephala	X	X	X
Calliandra calothyrsus	X		X
Gliricidia sepium	X	X	
Sesbania sesban	X	X	X
Sesbania bispinosa	X	X	X
Cajanus cajan	X	X	

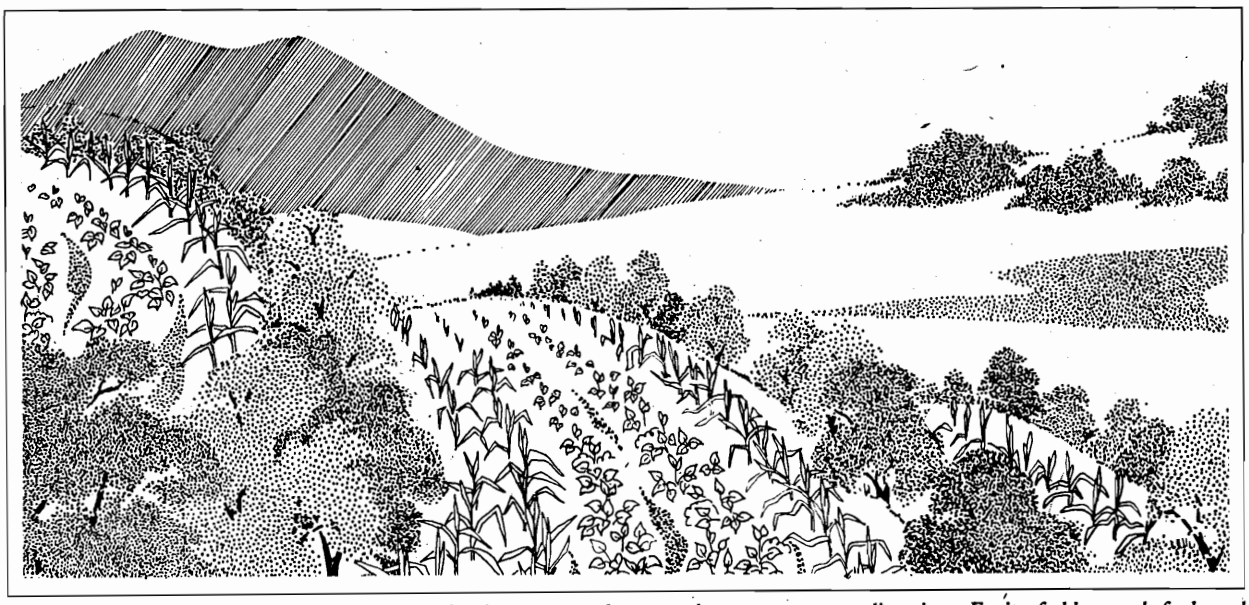
Wide Alley Planting

Wide alley planting is similar to hedgerow intercropping except the trees are planted in very widely spaced rows. Unlike intensive alley cropping, wide alley planting is carried out mostly for the wood and tree *products*, as crop yields are not significantly improved (and can even decrease slightly) by wide alley planting because of shade from the trees. Useful wide alley planting species are ones that are desirable because of some useable or saleable product (fruits, poles, timber, etc.). Deep-rooted trees are best for wide alley planting because they do not compete for water with associated crops. In wide alley planting, trees are not coppiced but are instead allowed to grow large in order to produce their desired product. Some canopy management can be practised to reduce shade on the crops.

In this system, trees are planted in rows 8-20 metres apart, with up to 4 metres between each two trees. Trees should *always* be planted in east to west rows to reduce the effect of shade on crops. As it is also desireable to plant along contours (as ploughing is done along contours), wide alley planting is best done only on parts of the *shamba* where *contours run east-west*. In a wide alley planting system, trees can be planted close together in rows and *thinned* (selectively cut) for woodfuel, poles and timber as they mature.

When selecting wide alley planting species, tree products should be given the first consideration. Fast-growing trees such as *Grevillea robusta* are often used in these systems to be regularly pruned for firewood. Indigenous trees such as *Markhamia* and *Cordia* are planted for the poles and timber they produce. Fruit trees are planted in rows to make the *shamba* function also as a fruit producing orchard. Trees with edible leaves are valuable as fodder reserves for the dry season. Beehives in wide alley planted systems provide a source of honey (which can be sold) while ensuring pollination of crops.

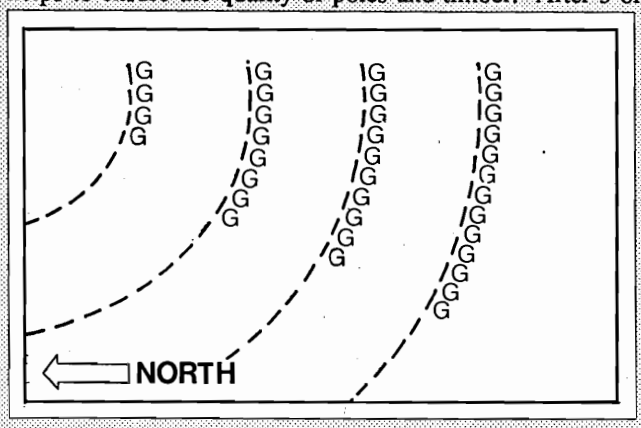
Although wide alley planting does not directly improve crop yields, it provides many of the agricultural benefits already described in the alley cropping section (i.e. green leaf manure, soil conservation). Leaf litter from trees such as *Grevillea, Markhamia* and *Cordia* can provide over two tonnes of humus per hectare per year.



Wide alley planting is carried out along land contours that run in an east-west direction. Fruit, fodder and fuelwood producing trees work well in wide alleys.

Example: Wide Alley Planting with *Grevillea robusta*

The example given is based on the one hectare farm illustrated on the left. The lines marked are contour lines. In this case, *Grevillea robusta* (marked as a "G") is planted in rows 15 metres apart, with trees 2 metres apart within the row. However, in order to minimise crop shading, *Grevillea* is only planted in the section of the farm where the contours run generally east-west. Once the trees reach a height of 4 metres, it is a good idea to start practising some canopy management by removing 10-20% of the lower branches at the beginning of the long rains every year (However, it is never advisable to remove more than 50% of a trees' natural canopy). This pruning also helps to ensure the quality of poles and timber. After 3 or 4 years, when the trees are small pole size, every other tree can be harvested for poles and woodfuel, leaving trees spaced 4 metres apart within the rows. In subsequent years, trees can be harvested as needed, continuing to remove every other tree, giving first 8 metres spacing between trees, then later thinning to 16 metres spacing between trees, then 32 metres, etc. After reaching the 8 metre spacing, it is possible to start replanting seedlings between the larger trees to ensure the future availability of the trees' products.



Fruit trees (e.g. grafted oranges, avocadoes or mangoes) can also be planted according to this scheme. The trees are still planted in the same east-west contour section of the *shamba*, but instead are planted 4 metres apart, and are never thinned.

TABLE 3.4: Useful Wide Alley Planting Species

SPECIES	SUITABLE AREAS		
	COAST	ASAL	HIGHLANDS
Casuarina equisetifolia	X	X	X
Gmelina arborea	X	X	
Azadirachta indica	X	X	
Dalbergia melanoxylon	X	X	
Brachylaena hutchinsii	X		X
Grevillea robusta			X
Markhamia spp.		X	X
Cordia abyssinica			X

All fruit and nut species can be planted on a farm in this system. See the tree list at the end of the chapter for other species.

Livestock Systems

Agroforestry can benefit farm systems that raise livestock. Dairies, ranches and even small farms with a few zero-grazed cattle can all use trees to increase their output. There are two silvo-pastoralism approaches depending on whether a farmer allows his livestock to graze or keeps them in zero-grazing enclosures:

Pasture Improvement.

In pasture systems, livestock browse or graze over an open area under the care of a shepherd. Trees can be used to improve any pasture system. The water retention, soil improvement and soil conservation services of trees make any pasture capable of producing more grass.

Trees also provide seed pods and leaves which can be eaten by livestock. Young trees germinating near established mother trees are also food for livestock. Trees in pasture land provide *shade* which improves the productivity of grazed livestock.

When establishing trees on pasture land, young seedlings, and small trees must be well protected from the livestock by building small fences around each tree. Such fences can be made of simple thorn tree branches, sticks, or even barbed wire. The fence must be maintained until the tree canopy has grown above the reach of livestock. Species appropriate for pasture improvement are ones which are known to give increased grass yields, such as *acacia* and *albizias*.

Example: Pasture Improvement

In pasture improvement, trees are planted in widely spaced rows which allow grasses to get plenty of sun. Trees should be planted on east-west contours to allow the option of later conversion to agricultural lands. Rows of trees should be 20 to 30 metres apart, while the trees should be 8 or more metres apart within the rows. (If desired, trees can be planted 4 metres apart and later thinned to 8 metres or more).

Table 3.5: Pasture Improvement Species

	SUITABLE AREAS		
SPECIES	COAST	ASAL	HIGHLANDS
Acacia albida	X	X	
Acacia tortilis		X	
Acacia abyssinica			X
Acacia lahai			X
Albizia spp.	X	X	X
Ficus spp.	X	X	X
Cordia abyssinica			X
Grevillea robusta			X
Zizyphus mauritiana	X	X	
Afzelia cuanzensis	X		
Tamarindus indica	X	X	
Prosopis spp.	X	X	

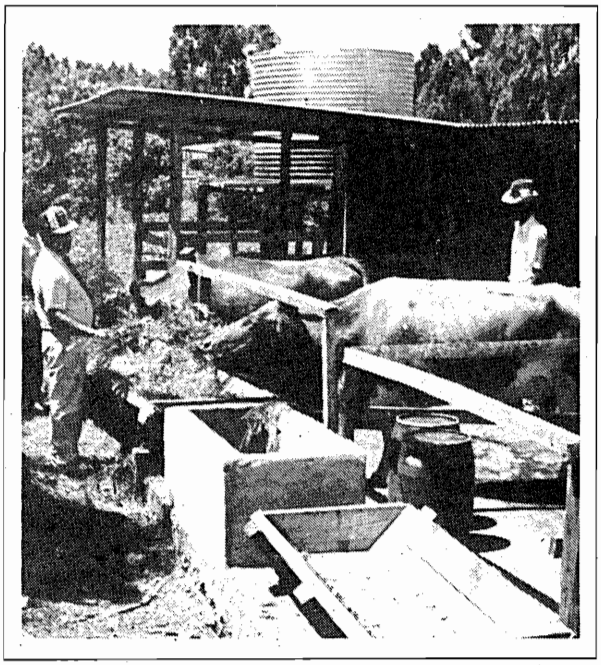
See the tree list at the end of this chapter for other species.

Zero Grazing

Zero grazing is a system in which livestock are not allowed to graze outside the enclosures in which they are kept. Food and water are brought to livestock and their wastes are regularly removed from the enclosure. *Bomas*, the established type of zero-grazing enclosures with mud floors, are now used throughout Central and Western provinces. However, modern zero-grazing *bomas* with *cement floors* and *feeding troughs* are much healthier.

Trees, shrubs and grasses provide fodder for livestock. These can be planted with crops as in intensive alley cropping systems, or they can be planted in fodder lots for pure fodder production, as described in this section. If the system is properly planned and managed, it can provide livestock with a continuous source of fodder.

Well-fed zero-grazed dairy cattle produce more milk, increasing the productivity of the dairy. Their wastes, used as fertilisers, improve yields when applied to food crops, cash crops or when returned to fodder grasses. Biogas digesters (see page 81) attached to zero-grazing enclosures improve the fertilising quality of livestock waste and produce combustible biogas fuel.



Zero grazing cattle being fed leucaena leaves. Agroforestry systems produce regular supplies of fodder even during prolonged dry seasons.

Example : *Leucaena* and Zero Grazing

Several dairies at the coast and other parts of Kenya already use *Leucaena* and napier grass "plantations" to feed their milk cows. Fast-growing *Leucaena* shrubs are intercropped as described under hedgerow intercropping, except in this case the "crop" is napier grass. The nitrogen-fixing properties of *Leucaena* improve the yields of napier grass. Leaves of *Leucaena*, being high in protein, are mixed with the napier grass fodder to make an excellent, nutritious feed supply for the cattle. In addition, *Leucaena* trees provide fuelwood that can be used by the dairy family and sold to nearby markets.

Leucaena intercrops well with napier, banda, and other grasses. In fodder-producing systems, harvesting should be timed so that the farmer always has a supply of fodder when he needs it. Fodder systems of *Leucaena* and grasses can be designed to provide fodder all year long on a rotational basis.

Table 3.6: Useful Fodder Lot Species

	SUITABLE AREAS		
SPECIES	COAST	ASAL	HIGHLANDS
SHRUBS/TREES			
Leucaena leucocephala	X	X	X
Calliandra calothyrsus	X		X
Sesbania sesban		X	X
Sesbania bispinosa	X	X	X
Gliricidia sepium	X	X	
Atriplex nummularia		X	
GRASSES			
Napier	X		X
Banda	X		X
Rhodes			X
Sudan grass	X	X	

Border Planting
(Hedgerows and Windbreaks)

Border planting is planting of rows of trees, shrubs or hedges on field and property boundaries. Small farms can especially benefit from using their boundaries for production of tree products. Every *shamba* should divide its borders, fields and compound using hedges and trees. Border planting improves overall productivity of farms by *protecting crops* and by *generating wood products*.

Windbreaks

Crop Protection. Trees planted along the boundary of a field from which direction the wind blows act as a *windbreak* for the crops. By reducing windflow across the fields, they decrease both water loss (from evaporation) and soil erosion rates. Evidence shows that in windy places crop yields can be increased from 20 to 40% through use of windbreaks.

Living Fences. Hedges or rows of close-planted trees are used as living fences to protect crops from wandering livestock and human beings. Trees are very good reminders of border lines and have been used traditionally for that purpose.

Tree Products and Services

As with any other type of agroforestry, the type of products produced by border planted trees depend on the need of the individual plot holder. Trees such as *Eucalyptus*, *Markhamia* and *Grevillea* are planted on boundaries as windbreaks to provide woodfuel and timber. Species such as *Euphorbia tirucalli* are planted as hedges in dry areas to provide fodder for goats and camels.

Besides marking boundaries and acting as windbreaks, border planted hedges and trees also enclose the compound, providing privacy and shade.

Example: Windbreaks

Windbreaks are located on the side of the property from which the prevailing wind blows. They are planted either as two rows of trees or as one row of shrubs and one row of trees. When using two rows of trees, the two rows should be 5-6 metres apart with a distance of 3-5 metres between trees. When using both trees and shrubs, the two rows should be four metres apart with the shrubs planted with spaces of 1-2 metres and trees spread 3-5 metres from each other.

Table 3.7: Useful Windbreak Species

	SUITABLE AREAS		
SPECIES	COAST	ASAL	HIGHLANDS
Eucalyptus spp.	X	X	X
Markhamia spp.		X	X
Grevillea robusta			X
Brachylaena hutchinsii	X		X
Vitex keniensis			X
Juniperus procera			X
Azadirachta indica	X	X	X
Casuarina equisetifolia	X	X	X
Gmelina arborea	X		
Jacaranda mimosifolia		X	X
Olea africana		X	X

See the tree list at the end of the chapter for other species and more details.

Example : Hedgerows

Neatly trimmed hedgerows make smart looking compound boundaries while providing privacy inside. They are planted as a single row of shrubs with about 15 cm spacing between each plant.

Table 3.8: Useful Hedgerows Species

	SUITABLE AREAS		
SPECIES	COAST	ASAL	HIGHLANDS
Doryalis caffra (Kei Apple)			X
Cupressus lusitanica (Cypress)		X	
Juniperus procera			X
Euphorbia tirucalii		X	
Pithecelobium dulce	X	X	
Parkinsonia aculeata		X	
Zizyphus mauritiana	X	X	
Oncoba spinosa			X
Prosopis spp.	X	X	
Erythrina abyssinica	X	X	X
Caesalpinia spinosa		X	X
Balanites aegyptiaca	X	X	
Acacia brevispica	X	X	

See the tree list at the end of this chapter for more species.

Woodlots

Woodlots are plots of land planted with *trees only* for the production of one or more tree products. Although woodlots do not involve farming, they are included in this agroforestry section because they can be established on parts of a *shamba* unsuitable for farming.

Depending on the type and area of trees planted, woodlots can provide large volumes of fuelwood, timber, poles, posts and even fodder. Woodlots help farmers meet their own tree product needs, as well as supplying a cash income from products sold. Woodlots give the *maximum* yields from *fast-growing* trees on any given unit of land.

Where to Start Woodlots

Woodlots should be established on parts of the farm which are not agriculturally productive. Trees can grow on very poor soils and thus make productive use of them. Woodlots *should not* be planted on good agricultural lands because of the importance of using high potential land to produce food and cash crops. Woodlots are planted on parts of the *shamba* that are either infertile, poorly drained, rocky, eroded, or very hilly. On large farms, uncultivated areas can be used to set up woodlots.

The size of a woodlot depends on the amount of land available for it, the desires and needs of the farmer, and the local market for the tree products. Woodlots can be as small as a 5 m x 5 m plot.

Establishing Woodlots

Only selected fast-growing trees are planted in woodlots. Since no crops are planted in woodlots there is no need to worry about crop compatibility. The main objective of a woodlot is to grow trees as quickly as possible.

Once the woodlot site has been chosen, the tree species and spacing (distance between each tree) must be decided upon. In Kenya, woodlots are usually planted with *Eucalyptus* and black wattle (*Acacia mearnsii*) because they are fast-growing and produce quality timber, posts and woodfuel.

Standard spacing of trees for woodlots is rows two metres apart with two metres between each two trees in the row (this is called 2m x 2 m). This spacing allows trees to grow with a maximum biomass production rate per hectare. However, trees are often planted in closer spacings (1 m x 1 m) to produce the small thin poles used in construction of houses. Spacing of trees depends on the type of wood product desired.

Harvesting and Management

As with tree spacing, the harvesting schedule depends on the wood product desired from the lot. The amount of time required for any tree to reach a given size, called the *rotation time*, depends on the *climatic zone* and *type of tree*. In the highlands, it takes between 3 and 7 years for maximum fuelwood production. Production of poles takes between 3 and 4 years. Posts have a rotation time between 8 and 10 years while that of timber may be longer than 30 years.

More than one type of product can be harvested from the woodlot through careful management. *Thinning*, the removal of trees in order to let other trees in a row grow, can yield fuelwood and poles. For example, in a closely planted woodlot, the first thinning after a few years can be used for firewood, and the next thinning can be used to provide posts.

Part of any lot can be left standing for production of posts and timber, while another part can be continually thinned, harvested and replanted for woodfuels and poles.

Table 3.9: Useful Woodlot Species

	SUITABLE AREAS		
SPECIES	COAST	ASAL	HIGHLANDS
Acacia mearnsii			X
Eucalyptys camaldulensis	X	X	
Eucalyptus microtheca		X	
Eucalyptus tereticornis		X	
Eucalyptus maculeata		X	X
Eucalyptus paniculeata		X	X
Eucalyptus saligna			
Eucalyptus globulus			X

Woodlots can also be used in the production of fodder, as in the zero grazing systems discussed earlier. In these cases, leguminous shrubs are not intercropped with fodder grasses, but in pure stands instead. In general, however, planting of both leguminous shrubs and grasses as a mixed feed for cows is better, and the positive interaction between the tree and the grass gives higher productivity.

Trees Around the House

Another place where trees can be planted on a farm is around the homestead. As trees around the house have little interaction with crops or livestock, this is not a true form of agroforestry. Nonetheless, trees planted around the house benefit the farmer. Such trees are generally planted more for beauty and shade

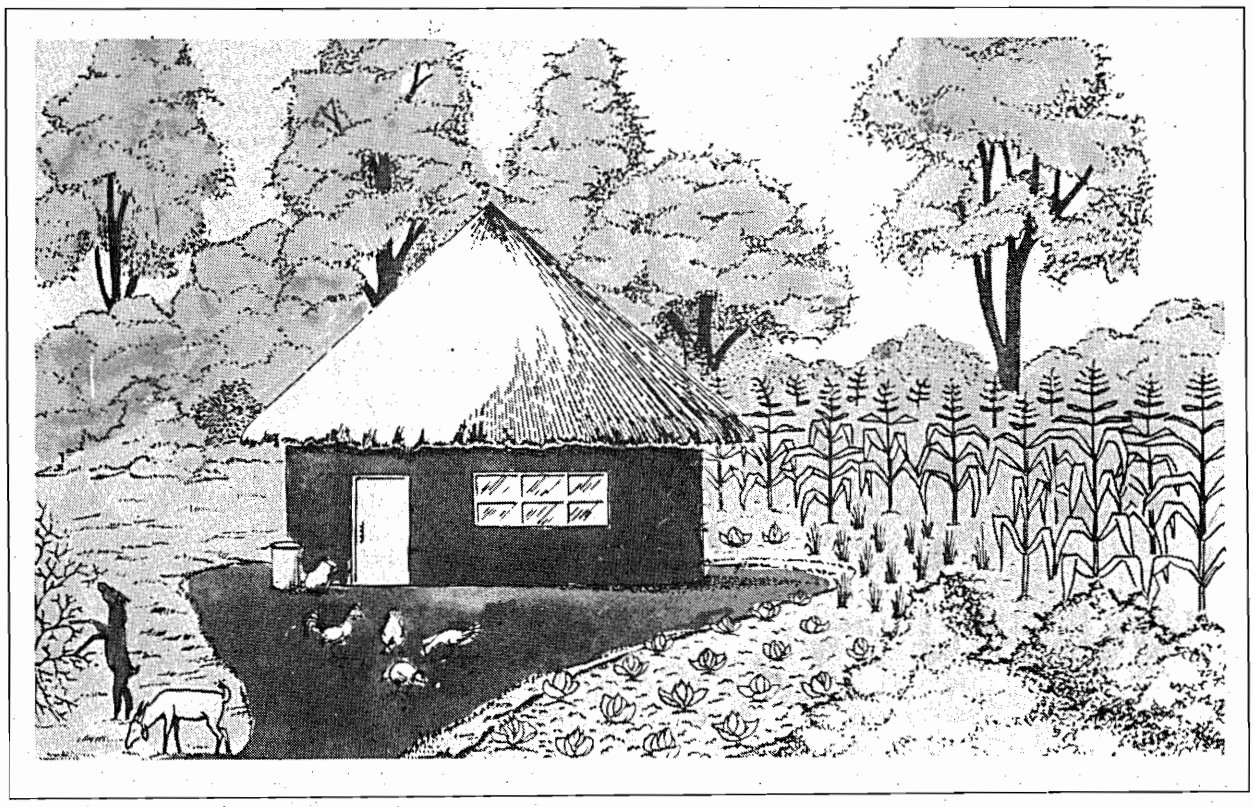
than for woodfuel. Fruit trees, which give shade and also provide food, are ideal for this purpose.

Typically only a few trees are planted in the compound. There are several considerations though, when planting these trees. They should not be planted too close to the house (i.e. within 5 metres) because when they grow their roots or limbs may damage the house. They should not be planted where their roots will damage underground pipes or drainage systems, or where their branches will interfere with telephone or electricity lines.

Thus, either only smaller trees should be planted, or the trees should be pruned to stop them from getting too big. A tree should not be allowed to get any taller than the distance between it and the house.

Table 3.10: Useful Trees for Planting Around the House

	SUITABLE AREAS		
SPECIES	COAST	ASAL	HIGHLANDS
Citrus (oranges, etc)	X	X	X
Mangifera indica (mango)	X	X	X
Psidium guajava (guava)	X	X	X
Persea americana (avocado)			X
Macadamia spp. (macadamia nut)			X
Cassia siamea	X	X	X
Acacia xanthophloea	X	X	X
Adansonia digitata	X	X	
Croton megalocarpus		X	X
Markhamia spp.			X
Tecoma stans		X	X
Moringa oleifera	X	X	
Parkinsonia aculeata	X	X	
Schinus molle		X	
Tamarindus indica	X	X	



Trees around the compound will add beauty, shade and functional wind breaks.

Table 3.3 — 3.10 Summary

Some Recommended Tree Species for Kenya

Species	English Common Names	Ecological Zones	Major Uses	Planting Niche
1. *Acacia abyssinica*	Umbrella Thorn	CH, WH	FW, P, NF, GM	PI, WR, TH
2. *Acacia albida*	Apple Ring Acacia	C, SA, LB	FW, P, T, FD, NF, GM	BW, PI, WR
3. *Acacia brevispica*	Wait-a-bit Thorn	C, SA, LB	FW, FD, NF, FE	H, PI
4. *Acacia lahai*	Red Thorn	CH, WH	FW, P, T, NF, GM	PI, WR, TH
5. *Acacia nilotica*	"Nilotica"	C, SA, US, LB	FW, FD, NF, FE	H, BW, PI, WR
6. *Acacia polyacantha*	Falcon's Claw Acacia	C, SA, US, LB	FW, P, FD, NF, GM	W, BW, PI, WR
7. *Acacia seyal*	White Galled Acacia	C, SA, US, LB	FW, P, T, FD, NF	BW, PI, WR, TH
8. *Acacia tortilis*	"Tortilis"	SA, US, LB	FW, FD, NF	PI, WR, TH
9. *Acacia xanthophloea*	Naivasha Thorn	C, SA, CH, US, WH, LB	FW, P, NF, M	PI, WR, TH
10. *Acrocarpus fraxinifolius*	Indian Ash	CH, US, WH, LB	FW, T, GM	BW, PI, WR
11. *Adansonia digitata*	Baobab	C, SA, LB	FD, FR, M	PI, WR, TH
12. *Afzelia cuanzensis*	Afzelia	C, LB	FW, P, T	W, BW, WR, TH
13. *Albizia spp*	Albizia	C, SA, CH, US, WH, LB	FW, P, T	BW, PI, WR, TH
14. *Anacardium occidentale*	Cashewnut	C, SA, LB	FW, FR	PI, WR
15. *Azadirachta indica*	Neem	C, SA, LB	FW, P, T, FD, GM, M	BW, PI, WR, TH
16. *Balanites aegyptiaca*	Desert Date	C, SA, US, LB	FW, P, T, FD, FR, FE, M	H, BW, PI, WR, TH
17. *Brachylaena hutchinsii*	Muhugu	C, CH, WH, LB	FW, P, T	W, BW, WR, TH
18. *Caesalpinia spinosa*	Caesalpinia	SA, CH, WH, LB	FW, P, FE	H, BW
19. *Cajanus cajan*	Pigeon Pea	C, SA, LB	FW, FR, NF	HI
20. *Calliandra calothyrsus*	Calliandra	C, CH, US, WH, LB	FW, P, FD, NF, GM	BW, ZG, HI, TH
21. *Cassia siamea*	Yellow Cassia	C, SA, WH, LB	FW, P, FD, GM	W, BW, HI, WR, TH
22. *Cassia spectabilis*	"Spectabilis"	CH, WH, LB	FW, P	BW, TH
23. *Casuarina equisetifolia*	Whistling Pine	C, SA, CH, US, WH, LB	FW, P, T, NF	W, BW, WR, TH
24. *Citrus spp*	Oranges, etc.	C, SA, CH, US, WH, LB	FR	W, BW, WR, TH
25. *Cocos nucifera*	Coconut	C	P, FR	W, BW, PI, WR, TH
26. *Combretum spp*	Combretum	C, SA, US, WH, LB	FW, P, T, GM	BW, PI, WR, TH
27. *Cordia abyssinica*	Cordia	CH, WH	FW, T, GM	BW, PI, WR, TH
28. *Cordeauxia edulis*	Jeheb-nut	SA	FD, FR, NF, FE	H, WR, TH
29. *Croton macrostachyus*	"Macrostachyus"	CH, WH, LB	FW, P, T, GM, M	BW, PI, WR, TH
30. *Croton megalocarpus*	Musine	SA, CH, US, WH, LB	FW, P, T	BW, PI, WR, TH
31. *Dalbergia melanoxylon*	African Blackwood	C, SA, LB	FW, T, FD, NF	W, BW, PI, WR
32. *Dalbergia sissoo*	Sissoo	C, SA, WH, LB	FW, P, T, FD	W, BW, PI, WR, TH
33. *Dombea goetzenii*	Mukeo	CH, WH	FW, P, T, GM	BW, PI, TH
34. *Dovyalis caffra*	Kei Apple	CH, US, WH, LB	FR, FE	H
35. *Eriobotrya japonica*	Loquat	CH, US, WH, LB	FR	BW, WR, TH
36. *Erythrina abyssinica*	Red Hot Poker Tree	C, SA, CH, US, WH, LB	FW, FD, NF, GM, FE	H, BW, PI, WR, TH
37. *Eucalyptus spp*	Gum Trees	C, SA, CH, US, WH, LB	FW, P, T, M	W, BW

38. *Ficus spp*	Figs	C, SA, CH, US, WH, LB	FD, FR	PI, TH
39. *Flemingia congesta*	Flemingia	C, LB	FD, NF, GM	ZG, HI
40. *Gliricidia sepium*	Gliricidia	C, SA, LB	FW, P, FD, NF, GM, FE	H, ZG, HI
41. *Gmelina arborea*	Gmelina	C, LB	FW, P, T, GM	BW, PI, WR
42. *Grevillea robusta*	Silky Oak	CH, US, WH, LB	FW, P, T, FD, GM	BW, PI, WR
43. *Jacaranda mimosifolia*	Jacaranda	SA, CH, US, WH, LB	FW, P, T	BW, WR, TH
44. *Juniperus procera*	E. African Pencil Cedar	CH, WH	FW, P, T, FE, M	H, BW, TH
45. *Leucaena leucocephala*	Leucaena	C, SA, CH, US, WH, LB	FW, P, FD, NF, GM	ZG, PI, HI
46. *Macadamia spp*	Macadamia Nut	CH, WH	FW, T, FR	BW, PI, WR, TH
47. *Maesopsis eminii*	Musizi	CH, WH, LB	FW, P, T	BW, WR, TH
48. *Mangifera indica*	Mango	C, SA, CH, US, WH, LB	FR	PI, WR, TH
49. *Markhamia lutea*	Markhamia	CH, WH, LB	FW, P, T	BW, PI, WR, TH
50. *Melia azedarach*	Persian Lilac	SA, US, LB	FW, P, M	BW, WR, TH
51. *Moringa oleifera*	Moringa	C, SA, LB	FD, FR, M	BW, WR, TH
52. *Newtonia buchanani*	Newtonia	CH, WH	FW, P, T	BW, WR, TH
53. *Olea africana*	Wild Olive	SA, CH, US, WH	FW, P, T, FR, M	BW, PI, WR, TH
54. *Onc ba spinosa*	Oncoba	CH, WH	FW, T, FE	H, TH
55. *Parkinsonia aculeata*	Jerusalem Thorn	SA, US, LB	FW, P, FD, FE	H, BW, WR, TH
56. *Persea americana*	Avocado	CH, US, WH	FR	W, BW, WR, TH
57. *Piliostigma thonningii*	Camel's Foot Tree	C, SA, US, LB	FW, P, FD, FR, NF, GM	BW, PI, WR, TH
58. *Pithecelobium dulce*	Manila Tamarind	C, SA, LB	FW, P, FD, FR, FE	H, BW
59. *Podocarpus spp*	Podo	CH, WH	FW, P, T	BW, TH
60. *Prosopis spp*	Prosopis	C, SA, US, LB	FW, P, FD, FR, NF, GM, FE	W, H, BW, PI, WR, TH
61. *Psidium guajava*	Guava	C, SA, CH, US, WH, LB	FW, FR	BW, WR, TH
62. *Schinus molle*	Pepper Tree	SA, US, LB	FW	BR, TH
63. *Schrebera alata*	Schrebera	CH, WH	FW, P	BW, TH
64. *Sesbania bispinosa*	Prickly Sesban	C, SA, CH, WH, LB	FW, P, FD, NF, GM	ZG, HI
65. *Sesbania grandiflora*	Agati	SA, LB	FW, FD, FR, NF, GM	ZG, HI, TH
66. *Sesbania sesban*	Sesbania	SA, CH, US, WH, LB	FW, FD, NF, GM	ZG, HI
67. *Syzygium cumini*	Zambarao	C, WH, LB	FW, T, FR	BW, WR, TH
68. *Tamarindus indica*	Tamarind	C, SA, US, LB	FW, P, T, FD, FR, M	BW, PI, WR, TH
69. *Teclea nobilis*	Teclea	CH, WH, LB	FW, P, T	BW, TH
70. *Terminalia brownii*	Terminalia	C, SA, US, LB	FW, P, T, GM, M	BW, PI, WR, TH
71. *Tipuana tipu*	Tipu	SA, CH, US, WH, LB	FW, P, T	W, BW, PI, WR, TH
72. *Trichilia roka*	Trichilia	C, CH, WH	FW, T, FR, M	BW, WR, TH
73. *Vitex keniensis*	Meru Oak	CH, WH	FW, T, FR	BW, WR, TH
74. *Zizyphus mauritiana*	Zizyphus	C, SA, LB	FW, P, T, FD, FR, FE	H, PI, WR, TH

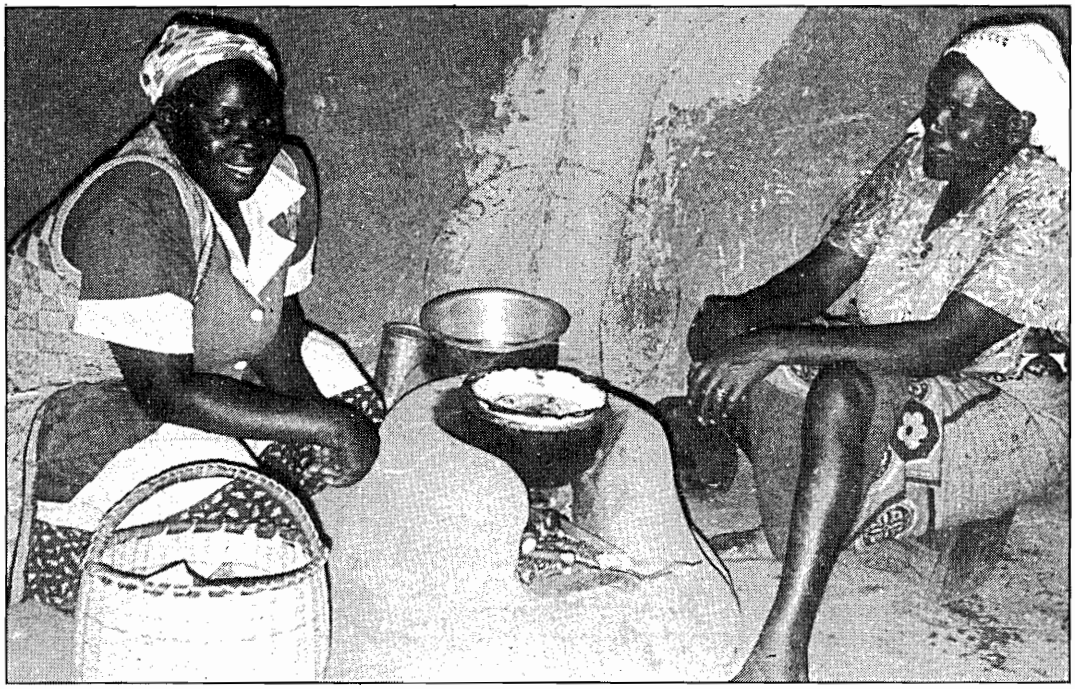
KEYS:

Ecological Zones
C = Coast
SA = Semi-Arid
CH = Central Highlands
US = Upland Savannas
WH = Western Highlands
LB = Lake Basin

Major Uses
FW = Fuelwood
P = Poles
T = Timber
FD = Fodder
FR = Fruits/Food
NF = Nitrogen Fixing
GM = Green Manure
FE = Fencing/Hedge
M = Medicine

Planting Niche
W = Woodlot/Orchard
H = Hedge
BW = Border Rows/Windbreaks
ZG = Zero Grazing (Fodder)
PI = Pasture Improvement
HI = Hedgerow Intercropping
WR = Wide Row Intercropping
TH = Trees Around the House

Source: Agroforestry in Kenya, Energy Development International, Nairobi 1987.



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Energy Conserving Stoves

Introduction

The danger posed to Kenya's environment by tree removal has been described at length in previous sections. Most of the current tree cutting practices are caused by the Kenyan population's increasing demand for agricultural land and, to a lesser extent, for wood products. Large areas of forest and bush are cleared each year for agricultural expansion. Charcoal makers fell trees and produce charcoal for use in cities. Wood haulers load felled trees into trucks and sell them to nearby rural schools, hospitals and homes as fuelwood. People all over the country prune branches and cut whole trees in their search for wood products. Because of the rising prices of wood and charcoal, and the fact that these resources are becoming scarcer, energy-saving methods and stoves are being adopted all over the country.

Many thousands of Kenyans now use wood and charcoal conserving stoves. Besides saving woodfuel and money, these stoves produce less smoke and are safer to use than traditional cooking methods. Most improved stoves are cheaply built from readily available materials by local craftsmen.

Any improved stove, *jiko* or three-stone fire is judged according to how well it serves its purpose. Fires often serve other purposes besides cooking. Some *jikos* heat the kitchen during cold weather. Some *jikos* give off light and serve as a centre of family activity during the evening. These other 'secondary' functions should always be considered when replacing a traditional *jiko* with an improved stove which may not fulfill any or all of these functions.

This section deals with the principle function of a stove, namely cooking food. In order to conserve woodfuel we are interested in cooking efficiently. This means that as much as possible of the chemical energy stored in woodfuel should be transferred as heat to the cooking pot.

Many factors affect heat transfer from the fire to the cooking pot. The woodfuel quality helps determine the amount of heat produced by the fire. The way a three-stone fire or stove is built affects the flow of heat from the fire. The shape and material of the cooking utensil determine how well it will absorb and transmit heat from the fire to the food. The methods used by the cook also help determine how much heat is wasted.

Below, the principles of wood burning fires and heat transfer applied in improved stoves are described: heat losses, advantages and disadvantages of traditional *jikos*, and finally, several improved stoves now being used in Kenya are described and illustrated.

Principles of Wood and Charcoal Burning

An understanding of *how woodfuels burn* is important for efficient use of fires. Well prepared and tended fires burn efficiently. Fires which are not well prepared or tended give off a lot of smoke and may burn out of control. Smoky fires are always wasteful because smoke is made of escaping unburned carbon particles.

Wood Compostion

Wood is composed of organic substances such as cellulose, hemi-cellulose, lignin and resins, as well as water and minerals (which leave *ash* when the wood is burned). These organic substances are made up of the elements; carbon (50%), oxygen (44%), and hydrogen (6%), which decompose into *volatile gases* (gases that will burn) when heated. The yellow flames seen in a wood fire are burning volatile gases which have been released by high temperatures.

The amount of heat produced by burning a piece of wood is called its *heat value* (or *energy content*). This value depends on the wood's *density, moisture content* and *ash content*. Heat values vary with different types of wood. Air dried *Acacia nilotica* wood, for example has a heat value of 15.0 - 16.8 MJ/kg. Resinous woods may have a higher heat value (at the same moisture content) while branches have a lower heat value.

Moisture content

Moisture content is the percentage of water contained in fuelwood. Wood with a high moisture content does not burn efficiently because much heat energy is spent evaporating water from the wood. It takes 2.4 megajoules of energy to expel each litre of water from pores in the wood. A high moisture content slows down the combustion process, cools the fire and causes incomplete burning of the wood, while producing much smoke. Air dried wood (two months) has about twice the heat value of freshly cut wood.

Measuring Moisture Content: Dry Basis and Wet Basis

The weight of any wood sample depends on its moisture content. Freshly felled green wood is often more than twice as heavy as air dry wood. Dry wood should be collected whenever possible because it is lighter and burns more efficiently than wet wood. The moisture content of wood is measured in two ways: on a *dry basis* and on a *wet basis*.

Dry basis expresses the moisture content as a percentage of the difference between the wet weight and the oven dry weight divided by the oven dry weight (the weight of the wood after it has been dried in an oven until its weight no longer decreases).

$$\text{Moisture Content (Dry Basis)} = \frac{\text{Wet weight - dry weight}}{\text{dry weight}} \times 100$$

Example:
Suppose the wet weight of a piece of wood is 7.5 kg and the oven dry weight is 6 kg.

The moisture content on a dry basis is:

$$\frac{7.5\ kg - 6.0\ kg}{6.0\ kg} \times 100 = 25\%$$

The moisture content on a wet basis is:

$$\frac{7.5\ kg - 6.0\ kg}{7.5\ kg} \times 100 = 20\%$$

Thus if the moisture content is 25% on a dry basis, it is 20% on a wet basis. If the moisture content is 100% on a dry basis, it is 50% on a wet basis. Moisture content can be measured as more than 100% on a dry basis, but never more than 100% on a wet basis. In Kenya, moisture content is typically measured on a dry basis.

Density

Density of fuelwood describes its weight per unit volume in kilogrammes per cubic metre. Fuelwood of a high density usually contains more energy per unit volume than less dense woods. Trees that produce dense wood include most *Acacia, Casuarina* and *Prosopis* species. Fast growing *Eucalyptus* species have a medium density and are favoured as firewood and poles. In general, slow-growing rangeland trees are more dense than trees that grow in high rainfall areas.

People planting trees for fuels should bear in mind that those with dense wood make the best firewood and charcoal. They should therefore choose tree species with dense wood that will grow in their climatic location. However, density is not the only important consideration for fuelwood species, and many Kenyans prefer to plant fast-growing species.

Ash content

Ash content describes the percentage of non-volatile substances in a fuel. Non-burning compounds of silicon and other minerals make up the ash remains of a fire. Wood usually contains about one percent non-volatile ash. Charcoal has a higher ash content of between 4 and 6%. Fuels such as rice husks, maize cobs and animal wastes have ash contents between 10 and 20%. Fuels with high ash contents have lower heat values than similar fuels with lower ash content as ash takes up volume but adds no heat to the fire.

Wood Combustion

Two factors affect the rate of combustion of dry wood: the surface area of the wood and the air supply to the fire.

Surface Area of Fuelwood

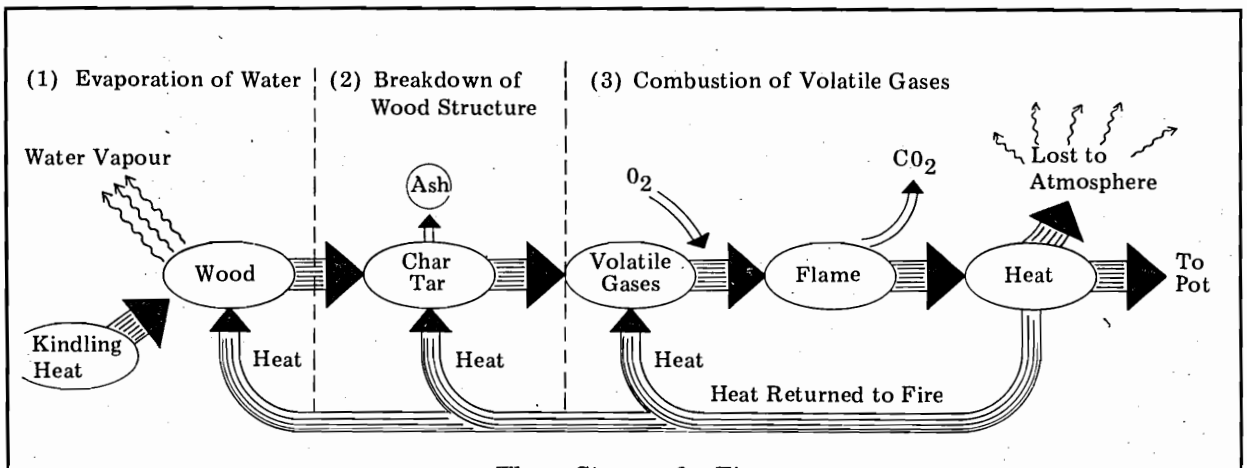
Wood is an insulator. It takes a long time for thick pieces of wood inside a fire to heat up and burn. Thick logs burn slowly and often incompletely. Smaller pieces of wood, with a greater surface area per unit volume, ignite quickly and burn completely. Small pieces of wood present more area to the fire and warm up quickly. Sticks of wood with a diameter between 3 and 5 cm are best for most cooking jobs, whereas larger logs are good for space heating and slow simmering.

Air Supply to the Fire

Too much or too little air causes fires to burn inefficiently. Fires require different amounts of air at different stages. During lighting, fires consume much oxygen, but by the time full combustion is reached they require less oxygen. Fires with carefully controlled air supplies burn more efficiently.

The Three Stages of a Fire

Lighting the Fire (25 - 100°C) Heat from burning kindling is applied to fuelwood during the first stage of the fire. This heat is used to drive moisture



Three Stages of a Fire

from the wood. During this stage, water vapour and carbon dioxide are given off with much smoke but without flames. The fire should be fanned continously because the fast-burning kindling requires a lot of oxygen.

The higher the wood's moisture content, the longer this stage lasts and the more energy wasted driving water vapour from the wood. The temperature will not rise above the boiling point until all of the water in the wood has escaped as vapour.

Release of Volatile Gases (150 - 225°C). The temperature again begins to rise once all of the free water has been expelled from the wood. Above 150°C, dark coloured tar appears on the surface of the wood and strong-smelling smoke is given off. At this stage the heated tars and charred wood began to chemically break down and escape as *volatile gases.*

As these volatile gases escape, they burn with a yellow flame. Wood fires are actually burning volatile gases rather than burning solid wood. These flames should be encouraged by fanning or blowing the fire to provide it with plenty of oxygen.

Full Combustion. Yellow flames burn steadily until the wood remains are glowing charcoal embers. This stage, full combustion, is when most actual cooking takes place over the fire.

At the high temperatures of full combustion, very little smoke is produced as all carbon particles burn completely. Carefully controlled high temperature fires are clean-burning and easy to use. Reducing the air supply helps control fires in the full combustion stage.

If the fire is not controlled, a turbulent combustion with large, noisy flames may occur. This rapid combustion is wasteful because it allows volatile gases to escape so rapidly that they do not burn completely. Rapid, incomplete combustion is best avoided by *controlling* the air supply to the fire. Slow-burning fires use less wood, burn completely and give off heat at a constant rate.

Building Fires

When building cooking fires, one should proceed from the lighting stage to the full combustion stage as quickly as possible. Below are some important fire building tips that will help in this process.

Use dry wood. The more moisture in the fuelwood, the longer the first stage of expelling water vapour will take and the less heat produced once it is burning.

Use small pieces of wood. Thick pieces of wood with a small surface area per unit volume take longer to burn.

This can be illustrated experimentally with two sheets of paper the same size. Fold one tightly in half four times. Do not fold the second one. Light them both on fire at the same time. Which one burns faster? Which one exposes a greater surface area to the outside?

Produce flames as quickly as possible. The temperature of the fire is steadily rising as long as there are flames. Blowing or fanning the fire will assist this process.

Keep the fire well-supplied with air during the first two stages. As more volatile gases are produced, they require more oxygen to react. In addition, heating cold wood requires constant flames. Bellows (devices that "blow" air into the fire) or hollow pipes are useful for directing air to the base of the flames.

Movement of Heat in Cooking Fires and Stoves

The last section discussed principles of combustion which are applied to produce the most heat per kilogramme of woodfuel. Once the cooking fire is properly prepared and tended, the next task is to transfer as much as possible of the heat produced *from the fire to the cooking pot.*

Around a fire, heat is always moving out in all directions by *conduction, radiation,* and *convection.* This section describes the three ways in which heat moves from hot places to cooler places. A good understanding of heat transfer will help one to make the best use of a fire.

Conduction

Conduction is the passage of heat through a substance from a hot area to a cool area. Heat energy is transferred by the vibrations of atoms close to each other in a substance. Atoms in hot substances pass their energy to more slowly vibrating atoms in cool substances. In this way, heat flows through substances.

The end of a cool metal spoon placed in a cup of hot tea becomes hot because of conduction. Heat moves into the metal spoon from the hot tea and through the metal to the end of the spoon.

Examples of good heat conductors are *metals* such as copper, cast iron, aluminium and steel. Water and stone are fair heat conductors.

Substances that do not conduct heat well are called *insulators*. When placed all around a hot object, insulators help the object retain its heat. Examples of materials that do not easily conduct heat are wood, ash, air and rubber.

Heat is lost from three-stone fires by conduction as the stones around the fire warm up and conduct heat into the ground. Metal *jiko*s also take heat from fires, conducting it to the outside. Heat moves through cooking pots and pans by conduction. Metal cooking pans conduct heat much faster than earthenware cooking pots, but earthenware cooking pots retain heat longer than metal pans because they have a higher thermal capacity. Electric stoves *conduct* heat from the hot plate to the pan with which it is in contact.

Radiation.

All bodies above absolute zero (-273°C) give off energy in the form of heat radiation. When radiation energy comes into contact with a solid, it is reflected, absorbed or transmitted by the solid.

The radiation given off by substances at ambient temperatures is not seen because it is at infra-red frequencies. The energy radiated from a warm rock or charcoal *jiko* can be felt but not seen.

Substances at high temperatures give off visible radiation (i.e. they glow). Coals in a fire give off a red glow. Burning gases from a wood fire radiate a yellow glow. Other burning gases (such as LPG gas or biogas) give off a very hot blue glow.

As distances between the source of radiation and the body receiving radiation increase, the heat received from the radiation source decreases rapidly. For example, one feels very hot sitting near a large fire, but after moving back a few feet one feels much less heat. Therefore, if heat is to be absorbed from a fire by a pot, the pot cannot be too far from the fire.

The type of surface that radiation strikes determines how well it will be absorbed. White and silver surfaces do not absorb radiation well. Black surfaces absorb radiation most effectively.

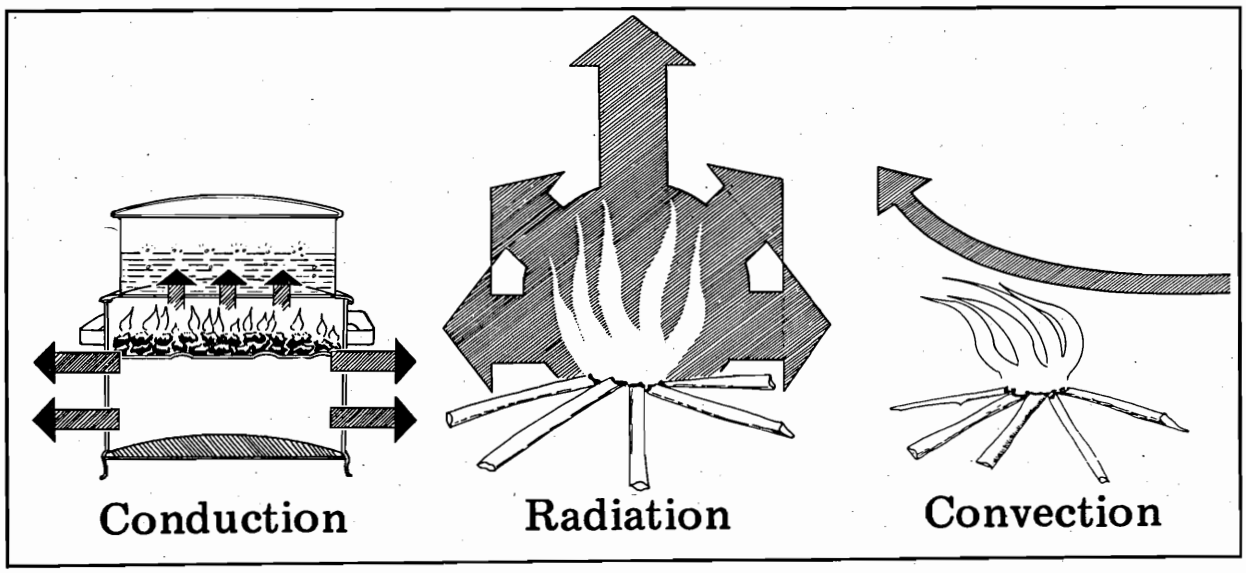
Much of the heat transfer in charcoal *jikos* occurs by radiation of heat from the fire to the cooking pot. If the fire is not enclosed, heat is lost to the atmosphere by radiation. Even if the fire is enclosed, as with a metal charcoal *jiko*, much energy may still be lost by radiation from the surface of the stove itself.

Convection

Convection involves the transport of heat by the movement of some sort of fluid, such as air or water. Hot air is displaced by more dense colder air, forcing the hot air to rise. The rising air carries heat with it. There are two types of convection: *Natural convection and forced convection.* Natural convection is the tendency of hot water or air to rise by itself. Wind blows hot air away from a fire by forced convection.

On one hand, convection currents are useful. Cooler air replacing the rising air contains oxygen which the fire needs. However, rising hot air carries heat away from the fire without transferring it to the cooking pot. Good cooking fires use convection currents to heat the pot by controlling the rate at which air enters and leaves the fire. Keeping fires as small as conveniently possible saves heat loss by convection.

Unprotected fires lose heat by natural convection. However, when exposed to the wind, they lose even more heat energy by forced convection. Steam rising from uncovered pots and pans carries away heat by convection. Even more heat is lost from pots and pans as moving currents of air take heat being radiated through the sides of the pots and pans.



Common Cooking Methods

The *three-stone fire* and the *metal charcoal jiko* are described below. Advantages and disadvantages of each of these are described. Heat losses that occur in charcoal *jikos* and three-stone fires as explained in the previous section, are also discussed.

Three-Stone Fires (Open Fires)

Three-stone fires are familiar to all rural Kenyans. Stones are arranged around an open fire in such a way that a cooking vessel can be placed over the fire. This has been the traditional method of cooking in Kenya and even now most rural families cook over three-stone fires.

Although three-stone fires use wood with a low efficiency (5-15%), there are many reasons why they are preferred:

- The fire can be controlled by moving the fuelwood into or out of the fire.
- Many types of fuels can be burned (wood, maize stalks, cobs, bagasse, etc.).
- The fuel does not have to be cut to a small size.
- The fire serves other purposes besides cooking such as space heating, lighting, keeping away insects and acting as a social centre at night.

Any three-stone fire can be made more efficient by using dry wood, wind shields and energy saving methods (see Improved Kitchen Management). Open fires have disadvantages:

- They are difficult to use during windy or rainy weather.
- Open fires in the kitchen present health dangers. Smoke from three-stone fires is bad for the eyes and lungs, and children often fall into the fire and burn themselves.

Three-stone fire heat loss:

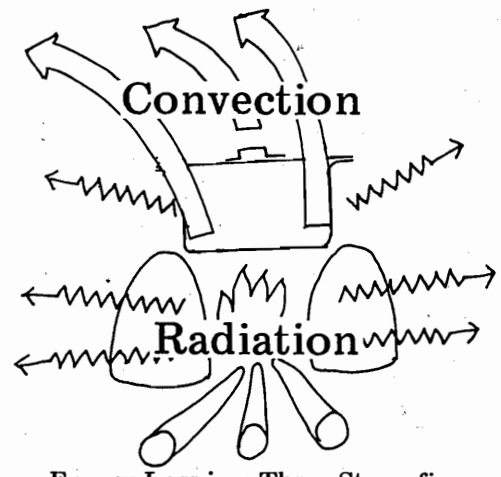
Radiation from fire to the atmosphere.
Because the fire is open, nothing prevents a great deal of heat from escaping as radiation.

Convection from fire to the atmosphere.
Hot gases rise from the fire upward into the atmosphere. Any wind blowing across the fire greatly increases losses by convection, as the hot gases no longer touch the pot.

Convection and radiation from pot to the atmosphere. The exposed cooking vessel gives off heat by both radiation and convection.

Metal Charcoal Jiko

Charcoal *jikos* have been use in Kenya for 60 years. Introduced up country by Indians during the building of the East African Railway, *jikos* are now the most common cooking tools in Kenyan urban areas.The reasons why charcoal is considered to be a wasteful



Energy Loss in a Three Stone fire

woodfuel have been discussed. Usually, less than a quarter of the energy in the wood used to kiln charcoal is available in the final product.

Nevertheless, charcoal can be transported profitably over long distances and conveniently stored in urban areas. For these reasons and because of its special properties, it is the most commonly used cooking fuel in cities. Charcoal stoves are made from scrap metal and sold in markets throughout Kenya.

Traditional models have several advantages:

- They use charcoal which is well suited for small stoves. Charcoal can be broken into small pieces, allowing the cook to use only as much fuel as necessary.
- They are small, cheap and portable.
- They are easy to light and use. The heat of the fire can be controlled by opening and closing the *jiko* door.
- Metal *jikos* fit any kind of pot.

There are several important disadvantages of using metal charcoal *jikos:*

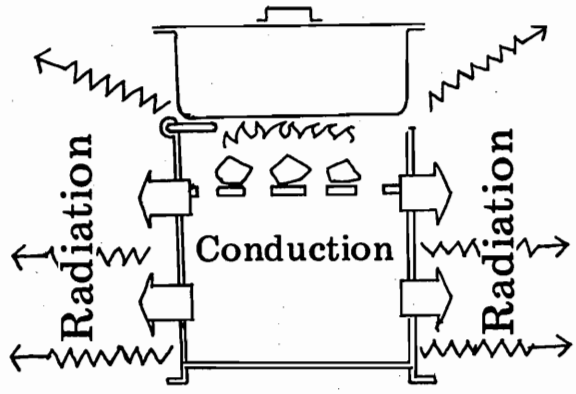
- They can cause burns to those that use them because their outer surfaces become hot.
- Charcoal gives off poisonous carbon monoxide as it burns, especially when the combustion process is incomplete. Charcoal *jikos* should always be used in well ventilated rooms.

NEVER USE CHARCOAL JIKOS IN CLOSED ROOMS.

Metal *jiko* heat loss:

Radiation from stove body to the atmosphere. Heat is radiated from the burning charcoal to the metal sides of the *jiko*. The metal *jiko* sides and grate conduct the heat to the outside and re-radiate it to the atmosphere. Much heat is lost to the atmosphere in this way.

Convection and radiation from cooking utensil to the atmosphere. Because pans sit on top of the *jiko* they give off heat to the atmosphere in



Energy Loss in a Traditional Jiko

all directions. Currents of air take heat away from the pot by convection. All surfaces of the pot give off heat by radiation.

Principles of Improved Stoves

The previous section discussed advantages and disadvantages of traditional cooking tools. Because there is much *heat loss* from the metal *jiko* and open fire during cooking, energy can be saved by improving the use of heat. When improving stoves, the advantages of traditional stoves should be made part of the new design whenever possible.

Two major improvements will increase the performance of any cooking fire:

(1) *Enclosing and insulating the fire*
(2) *Controlling the airflow through the fire*

Enclosing the fire helps prevent wind and draught from carrying heat away by forced convection. It also enables more of the hot gases in the fire to transfer their heat to the cooking pot. A wall around the fire limits heat loss by radiation to the atmosphere and re-directs heat onto the cooking pot. Also, children are less likely to suffer burns from enclosed fires.

Controlling the airflow through the fire makes it more manageable. By increasing the airflow the temperature can be increased, and by decreasing the airflow the temperature can be lowered. Proper airflow ensures that fuels burn completely, thereby producing less smoke. Controlling airflow by means of a chimney directs smoke out of the kitchen.

Stove Parts that Enclose and Insulate the Fire

The Firebox

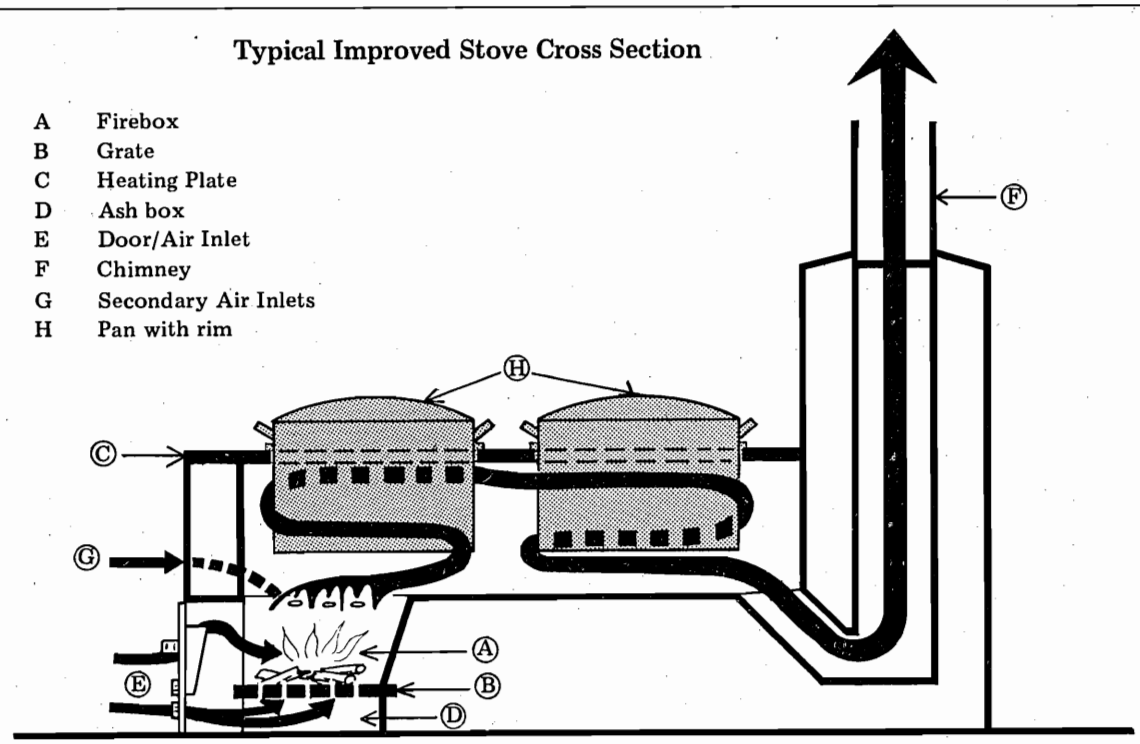
Also called the *combustion chamber*, the firebox is the enclosed part of the stove in which wood burns. It keeps heat inside the stove by preventing radiation and convection losses. Well-designed fireboxes direct the fire's heat to the cooking pot or pan. Fireboxes are built of materials such as ceramic bricks which can withstand high temperatures.

There is often a clay or double piece metal *outer wall* surrounding the firebox which helps insulate and retain the heat of the fire.

The Grate

The grate is a perforated platform at the bottom of the firebox upon which burning wood and embers sit.

Typical Improved Stove Cross Section



Grates allow ash to fall into the ashbox below while they retain burning wood and glowing embers. Air is also fed into the fire from below the grate, pre-heated by glowing embers as it passes through.

Heating Plate

Heating plates are thick sheets of metal which enclose the top of the firebox on some stoves. They make the top of the stove (the part that is most used) sturdy and long-lasting while they prevent loss of heat by convection. Heating plates have holes cut in them which allow specially-sized *sufurias* to fit into them. These holes allow the base of the *sufuria* to sit *inside* the top part of the firebox. Situated like this, the *sufuria* quickly absorbs radiation from inside the firebox and does not radiate as much heat to the atmosphere.

Ash Box

The ash box is the space below the grate into which ash falls. Air in the ash box is pre-heated before moving through the grate into the fire.

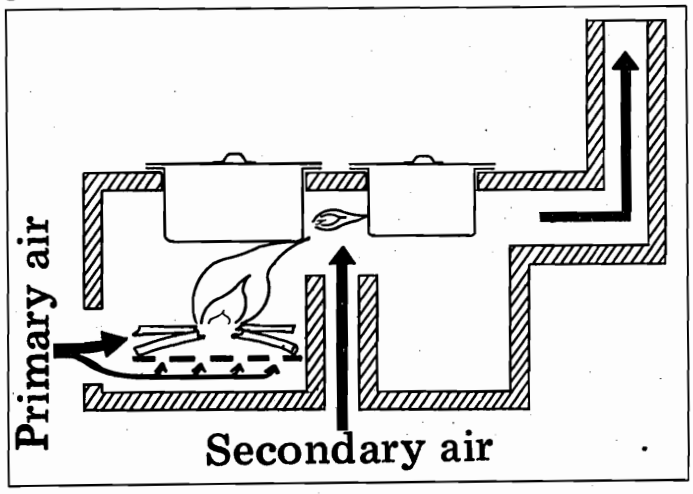
Stove parts that control airflow through the fire

The Door/Air Inlet

Besides enabling loading and lighting of woodfuels in the firebox, the door serves an important purpose in controlling airflow through the fire. On some stoves there is an *air inlet* in the door that allows air to pass into the firebox. Air inlets often have a passage which *pre-heats* the air before it enters the firebox (cold air cools down the fire). On some stoves, the door opening serves as an adjustable air inlet, opened and closed by a hinged piece of metal or block of clay.

Because airflow in improved stoves is limited, it is sometimes necessary to let air enter the firebox in more than one place. *Primary air* is air that enters the fire through the air inlet and from *below* the grate. It is the main source of oxygen for combustion.

However, sometimes the primary air inlet does not provide enough oxygen to burn all of the volatile gases in the upper part of the firebox. These gases may thus escape unburned because of a lack of oxygen. *Secondary air*, provided by separate air inlets that lead from outside the stove to the firebox, enables complete burning of volatile gases in the combustion chamber (see diagram).

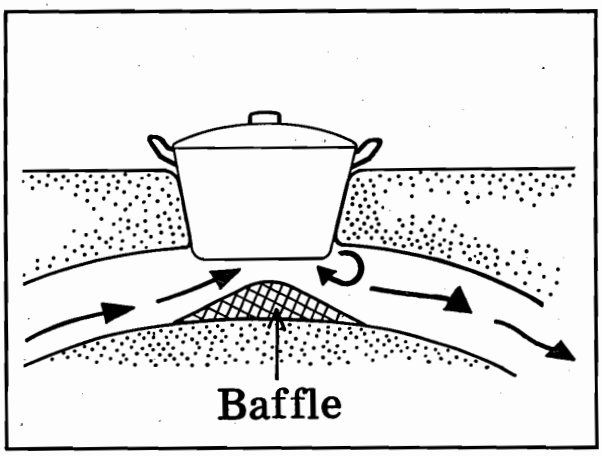


Dampers

Dampers are movable plates which may be opened or closed to control the amount of air moving through the fire. The damper may be located near the chimney or in the air inlet. There are may be more than one damper which controls air flow through the chimney and other stove chambers.

Baffles

Baffles are barriers in the stove's air passages which slow down hot gas movement, allowing it more time to transfer its heat to the cooking pot. Baffles prevent hot gases from travelling in a straight line. One type of baffle directs hot gases in a circle around the pot. Another redirects air away from the chimney passage and back toward the cooking vessel. They are placed near the door, at the exit of the firebox, or near the chimney, where they can best redirect the hot gases.



The Chimney

The chimney is a wide pipe connected to the back part of the stove, and extending up and out of the kitchen. It has two important functions in stove operation. Firstly, convection currents (called the *draught*) that move up the chimney *pull* air into and through the stove. Secondly, the chimney is a passage-way for smoke and unwanted gases to the outside. A well-designed chimney controls air movement through the fire and keeps the kitchen free of smoke.

Chimneys extend one and a half to two and a half metres above the roof of the kitchen. The exact size of the chimney depends upon the type and size of the stove. Proper sizing of chimneys is important to prevent malfunctioning of the stove.

Atop the chimney is a cone-shaped device called the *cowl* which prevents rain from entering the chimney and helps increase the draught.

Chimneys must be cleaned regularly to prevent accumulation of tar, soot and creosote which will eventually either catch fire or block the chimney.

Stove Materials

Stoves have been made from mixtures of mud, clay, ash, sand and even termite-hill earth. Stove bodies have also been built with bricks and concrete blocks in some local institutions. Heavy cast-iron wood burning stoves are also available in Kenya.

Almost all stoves require some metal parts and metal craftwork. Many stoves have metal doors. The grate is often made from cast iron. Chimneys are most commonly made with sheet metal. Many stoves have a thick steel plate as their top surface.

Stove building is a profession. Much training and experience is required to build proper stoves. Therefore, those who want to install stoves should seek help from qualified people.

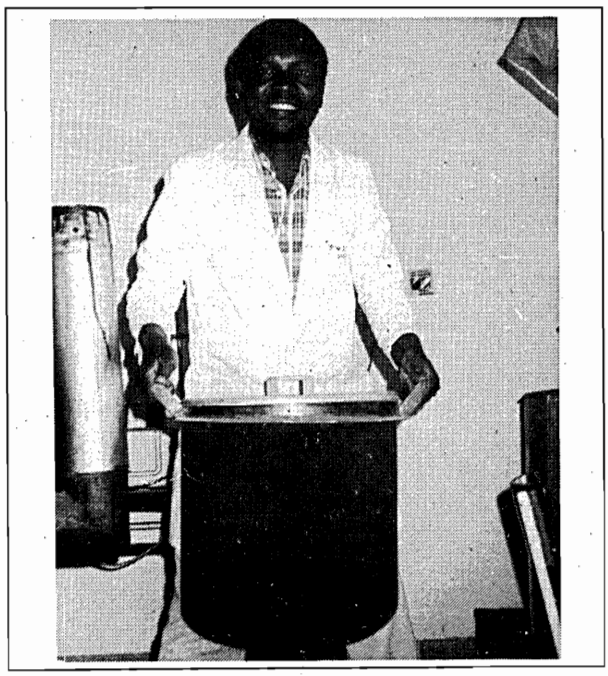
Cooking Vessels

The type of cooking vessel used during meal preparation has a great effect on cooking efficiency. Cooking vessels of the wrong material, shape or size may cause heat to be wasted. Improved stoves should be built to fit the cooking vessels that are available in local kitchens.

The shape of the cooking vessel should, for best results, present the largest possible heating surface to the fire. Pans that *sit in the firebox* present a large surface area to the fire. Cooking vessels with rounded bottoms also absorb heat from fires better than flat bottomed vessels.

Two types of cooking vessels are used commonly in Kenya: *pots* and *pans*. For the purposes of this book, pots are made from fired clay and pans are made of various metals.

Clay pots have been made and used to cook food locally for hundreds of years. Although pots do not heat up quickly because the clay material is not a good conductor, they store heat very well. Thus clay pots are well suited for simmering slow cooking dishes such as "*githeri*" and millet porridge. Clay pots keep food warm for a long time.



Bellerive stove cooking vessel. This pan has a rim which allows it to sit inside the firebox.

Metal cooking pans (*sufurias*) were first imported by Indian traders long ago. Now most Kenyans prefer to cook with metal pans because they are easy to use. Pans are commonly made of aluminium, cast iron, or stainless steel. Cast iron pans are heavy, retaining heat better than other metals, but they are also more costly that other pans. *Sufurias* are commonly made of a light drawn aluminium which heats up quickly and is thus useful for fast cooking.

Pans that become black on the bottom do not need to be cleaned because the black colour absorbs heat quite efficiently. However, a thick tar or soot build up should be scraped off because it insulates the metal, and can catch fire.

Some features to consider when choosing pans are listed below:

They should be made from thick metals. Thick metal pans retain heat longer and last longer than thin pans.

They should have tight fitting lids. Lids prevent heat from escaping, allow vapour to condense inside pans and keep ashes and insects out of the cooking food.

They should have a rim. Rims allow easy handling of pans. On improved stoves which have heating plates, *sufurias* with rims that enable them to fit into the firebox make best use of the heat.

Improved Kitchen Energy Management

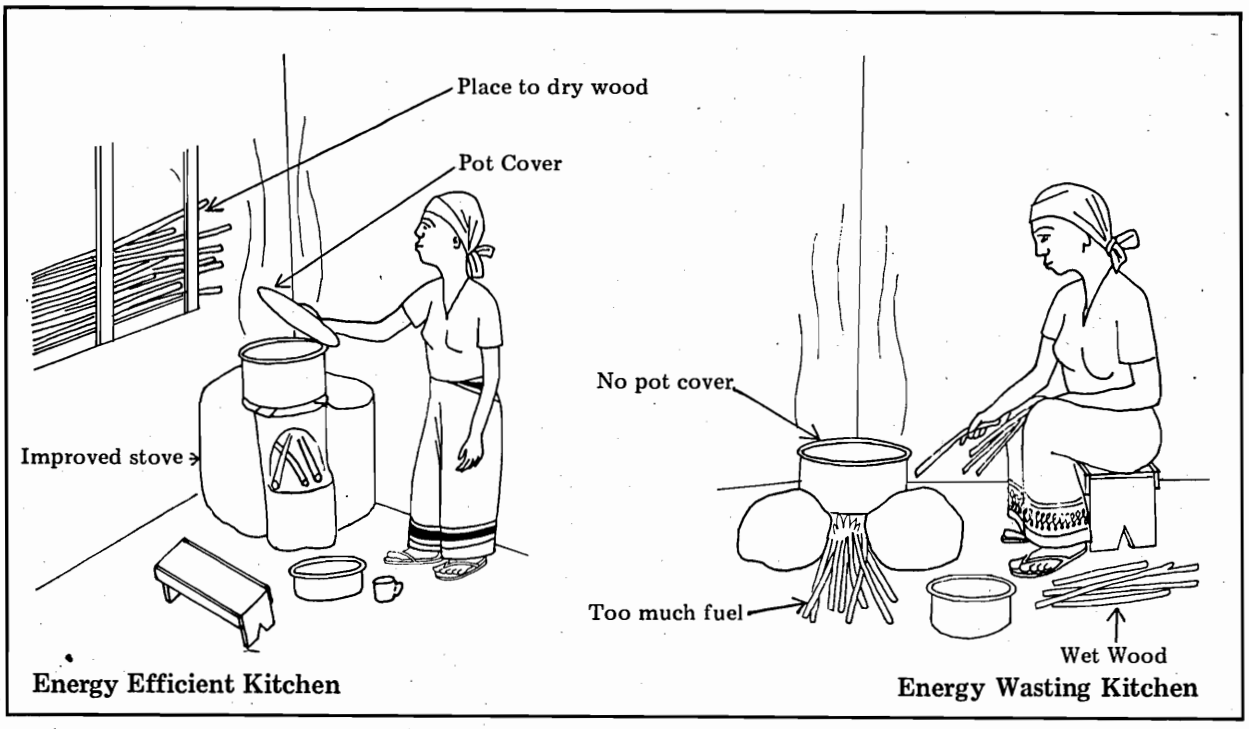
The ways in which cooks manage the kitchen determines each kitchen's energy efficiency. Firewood should always be prepared by drying and chopping it to size that will fit in the stove. Open fires should be carefully constructed and tended. Careful attention should be given to food preparation methods and use of cooking utensils.

It is recommended that improved stoves be used whenever possible. Wastefully used open fires burning wet wood may only have an energy efficiency of 5%. By using the improved cooking methods listed below, the efficiency of the three-stone fire can be raised to 20%.

Choosing and Preparing Fuelwood

Use wood instead of charcoal whenever possible. Use of fuelwood is always more energy-efficient than use of charcoal.

Always use dry wood. Freshly cut wood has a much higher moisture content than dried wood. Hence, much energy is wasted expelling moisture from wet wood. Wood should be dried for about 2 *months* to get maximum energy efficiency from it. Wood will dry more quickly if it is split to increase its surface area.



Build places to dry wood. Wood is often stored in rafters above the fire to be dried by rising warm air. Some stoves have shelves built below them in which drying wood is stored. Many homes and institutions build sheds for storing and drying wood.

Use wood cut to a proper size. Sticks with a small diameter present a greater surface area per volume to the fire, heat up quickly and burn completely. They also fit easily into the cookstove and allow the stove door to be closed.

Constructing Fires

Use a wind shield. Wind shields prevent wind and draughts from carrying heat away from the fire. Wind shields are made from sheets of "*mabati*" (placed in the direction from which the wind blows) or from mud or stone walls built around the fire.

Choose and arrange stones in open fires carefully. Choose stones with a shape that will fit pots and pans securely. Carve ledges in the stones so that the pots and pans will be stable during stirring. Build open fires on large flat stones so that heat is captured and radiated back to the fire. Some areas sell 3 legged metal stands which accommodate various pot sizes. These can be inserted in the fire and used to hold pots instead of stone ledges.

Use the optimum pot-fire distance. Make sure that the pot or pan is at the most effective distance from the fire. Cooking utensils placed too far from the fire absorb much less heat from radiation and convection. Optimum pot-fire distances are between 10 and 12 cm in wood fires and about 5 cm in charcoal fires.

Always build the smallest fire necessary to cook each meal. Any extra wood used is wasteful.

Food Preparation and Cooking Management

Always cover cooking food with lids or plates. Uncovered pots and pans allow much heat to escape in the form of convected or radiated energy.

Boil food slowly. There is no need for a roaring fire underneath a pot of "*githeri*" which will cook just as fast over a small fire. Simmering cooks food just as fast as rapid boiling while it ensures that the nutritional value of the food is retained. Once food in a covered pot has been brought to a boil, it is often not necessary to add more wood to the fire, because the retained heat of the fireplace, stove and pot will cook the food slowly.

Soak hard foods. Hard foods (e.g. maize and beans) soaked overnight take much less time to cook than unsoaked food, and hence consume much less fuel during cooking.

Cut meats, potatoes and vegetables into small pieces before cooking them. Food cut into small pieces cooks faster. Like small pieces of wood, small chunks of food have a large surface area and hence absorb heat faster.

Teach children and house helps to conserve energy. When everyone in the household practices energy-saving measures, the combined energy savings will be much greater.

Keep cooking vessels and stoves clean. Soot accumulating on the bottoms of pots and pans will reduce their ability to transfer heat. Stove parts (especially chimneys) should be kept clean and well maintained. If stoves or pans are not clean, the danger of a fire breaking out is increased.

Local Improved Stoves

Kenya is among the leading African countries in improved stove technology. Thousands of Kenyan families and institutions now use energy conserving stoves. Many organisations are promoting, building and selling improved stoves. This section describes some of the successful stove models.

The charcoal burning *Kenya Ceramic Jiko* is the most widespread improved stove. Hundreds of thousands of city dwellers now use this stove which greatly reduces charcoal consumption.

Woodburning *Maendeleo* and *Pogbi* stoves are being rapidly adopted by rural families, especially in areas where wood must be bought. The *Maendeleo* stove is cheap, simple to construct and as easy to use as the three-stone fire. The Pogbi stove has been purchased by hundreds of families around Ruiru because it uses fuel more efficiently than the three-stone fire.

Institutions buy fuelwood by the tonne. They can significantly reduce their fuelwood expenses by cooking with improved stoves (especially if they now cook over open fires). The *Alfa Laval Institutional Stove* has proved to be effective in thousands of schools, hospitals and other institutions all over Kenya. The *Bellerive Community Stove*, both cheap and energy-conserving, has been constructed in over 200 institutions over the last two years. Additionally, an institutional stove made by *Ital Products* has proven to be very efficient

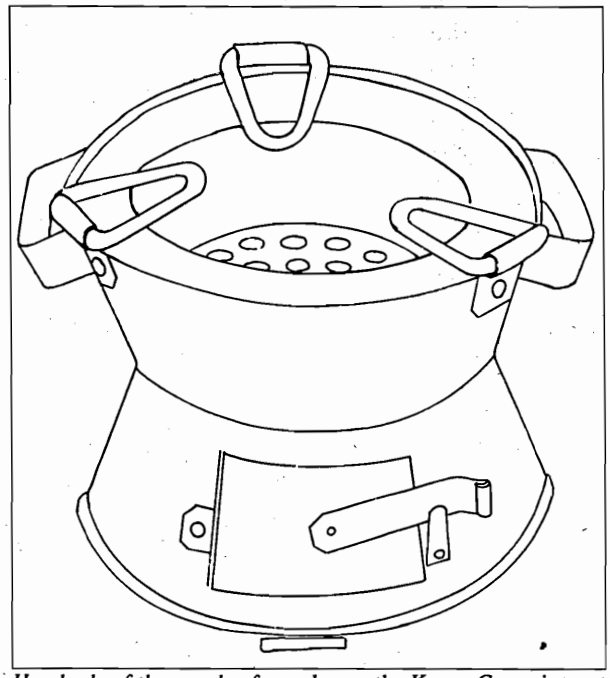
The Kenya Ceramic Jiko

High prices and decreasing resources of charcoal in Kenya have led to the design of *jikos* that burn less fuel. In Nairobi, for example, a family typically burns over 100 kg of charcoal per month (2-3 bags) with a traditional metal *jiko*. They spend a large part of their income just buying fuel.

Since improved charcoal *jikos* were displayed at the 1981 United Nations Renewable Energy Conference in Nairobi, many people have been designing improved *jikos* that can be locally produced. Mr. Maxwell Kinyanjui and Mr. Keith Openshaw, in particular, were involved in the design of better charcoal *jikos*.

The Ministry of Energy and Regional Development (MOERD) sent Mr. Kinyanjui with members of an Improved Stove Working Group to Thailand to study efficient stoves there. Thai stoves (or Thai buckets) are made out of fired clay with or without an outer metal container and a middle insulating layer of ash. In Kenya, a stove was designed (using features from the Thai stove) with a fired-clay lining and a metal body.

MOERD contracted for five hundred of these clay-lined improved *jikos* to be made by a local company. They also contracted for field tests of the stove with the Kenya Energy Non-Governmental Organisations Association (KENGO). These improved *jikos*, with a ceramic liner like the Thai Stove and a metal body similar to the traditional *jiko*, saved much fuel but were quite fragile.



Hundreds of thousands of people use the Kenya Ceramic Jiko due to its energy efficiency and convenient design.

Therefore, the improved *jiko* was re-designed several times to make it more sturdy. The present Kenya Ceramic Jiko (KCJ) is an outcome of those improvements. It has performed so well that it is now built and used in urban areas all over the country.

Description

The Kenya Ceramic Jiko is a light, portable charcoal stove. Its bell-bottom shape has two parts; a combustion chamber on top and an ash box on the bottom. The upper part of the *jiko* is lined with a bowl-shaped *ceramic insert* that receives the charcoal and acts as a firebox. The stove's grate has about 20 holes in the bottom part of the ceramic liner which hold the charcoal and allow air to enter the firebox from below. The liner is held in place by an inverted cone-shaped metal cover with sturdy handles. Like the traditional *jiko*, the KCJ has 3 hinged rings which function as rests for the cooking vessels.

The lower part of the *jiko* is a cone-shaped metal chamber which serves as the ash box. A hinged door is the stove's *air inlet*, allowing control of air flow to the fire. The chamber is wide enough to allow for easy lighting and adequate inflow of air.

The KCJ is operated in the same way as the traditional *jiko*. Charcoal is placed in the ceramic liner and some type of kindling is lit in the chamber below. The burning kindling ignites the charcoal through the ceramic grate. The door to the ash-box is left open during the lighting stages to allow air to reach the charcoal from below. *Jikos* are usually lit outside with their open doors facing the wind, which fans the fire.

When the charcoal begins to burn steadily, convection currents pull air into the fire through the grate. At this point, the door is closed and the stove is carried inside. The cooking vessel is placed on the rings of the *jiko*.

Advantages of the KCJ

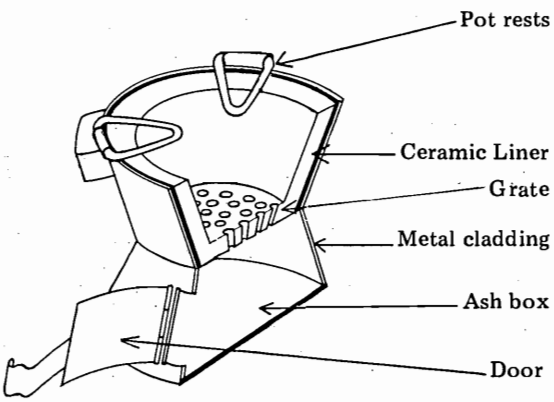
The most important feature of the KCJ is the ceramic liner which *insulates* the *jiko's* sides and directs heat onto the pot or pan. The KCJ was tested and compared with the traditional metal *jiko* experimentally at Kenyatta University. Three important test conclusions are listed below:

- The KCJ uses *30-50% less fuel* than the traditional metal *jiko*.
- It *boils water faster* than the traditional metal *jiko* (33% less time).
- It produces *20% less poisonous carbon monoxide* than the traditional metal *jiko*.

The ceramic liner reduces energy loss by greatly reducing conduction and radiation of heat through the sides and grate of the *jiko*. In fact, the insulation provided by the ceramic liner *returns* heat to the fire, making the fire burn more completely at a higher temperature. The liner's shape causes heat to be directed upward to the pan. The end result is a greater amount of heat transferred to the pot for each mass of charcoal used.

The 30-50% fuel savings over the traditional *jiko* result in a reduction of monthly fuel costs. With the KCJ a city dweller who had been using six to nine bags of charcoal every three months could expect to use only three to four bags of charcoal in the same period. The KCJ can pay for itself in a single month with money saved on charcoal.

KCJ Cross Section



The KCJ has other advantages. It cooks faster because it brings water to boil faster (of course, simmering will take the same time). Its ceramic insulation makes the outside walls cooler, reducing the danger of burns to people in the kitchen. The kitchen atmosphere is made healthier because the KCJ produces less carbon monoxide and smoke. In addition, well constructed ceramic *jikos* have a longer lifetime than metal *jikos*.

Distribution

Since 1982 the Kenya Renewable Energy Development Project (KREDP) has been supporting the development and distribution of the KCJ. They have supported stove workshops which train local artisans to build the stove. They have also promoted the KCJ through newspapers, leaflets and various organisations. As of December 1986, over 250,000 KCJ had been made and sold in Kenya.

The ceramic liners are, for the most part, produced by local potters. Meanwhile, the metal covers are produced by *jua kali* artisans. The *jikos* are assembled and sold in markets all over the country. Stove-building workshops are especially active in Nairobi, Coast, Central and Nyanza Provinces. KCJs are also now being exported to Sudan, Uganda, Rwanda and Tanzania.

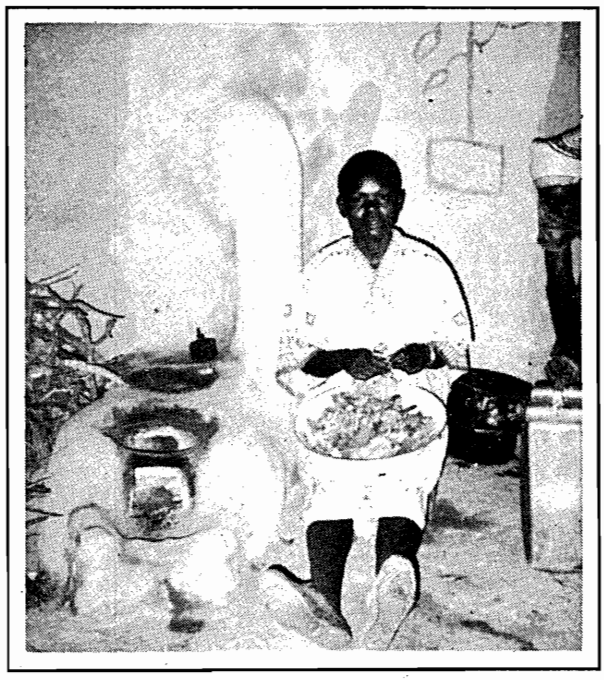
The Kenya Ceramic Jiko is an example of a cheap, modern, energy-saving stove that has been very successful.

Maendeleo Stoves

Cheaply and easily constructed, *Maendeleo* stoves are now increasingly used by women in Kenya. There are two types of *Maendeleo* stoves, the *Maendeleo* 1 and 2. This section describes the first model.

The stove was developed through efforts of the *Maendeleo ya Wanawake*/GTZ Women and Energy Project to improve the three-stone fire. Although many improved stoves provide benefits to the cook such as reduced fuel consumption and smoke production, most stoves do not give the greatest advantage of the three-stone fire: *no cost*. Often women in rural areas do not have money to buy improved stoves.

In Kiambu, Murang'a, Kisii and Meru, the



Maendeleo stove with chimney in Kisii. These stoves are twice as efficient as three stone fires.

Maendeleo ya Wanawake/GTZ Stove Programme has attempted to improve the three-stone fire at minimum cost. In 1983 a stove design from Burkina Faso was adopted to fit Kenyan women's indoor cooking preferences. This design replaced the three stones of the open fire with six fired clay bricks. The bricks were encased in a strong mud material which could support *sufurias* during the cooking of *ugali* or *githeri*.

Called the *Six Brick Stove*, it is now used in many Central Province kitchens because it saves energy and fits any pot size. However, the Six Brick Stove must be constructed *exactly* in order to save fuel, and it is difficult to train individuals to construct it properly.

In 1985, stove designers replaced the six bricks used in stove construction with a cylindrically shaped ceramic liner. The liner is pre-moulded to serve as the stove's *firebox, air inlet* and *pot rest*. Local materials (such as those used in the area for building houses) are packed around the ceramic liner to build up the stove walls. During field tests, rural women quickly learned to build this stove, now called the *Maendeleo 1 Stove*.

Description

This stove (like the Kenya Ceramic *Jiko*) is built around a fired ceramic liner which can withstand high temperatures for a long time without cracking. The space inside the liner is the stove's firebox. One side of the liner has an arched opening which serves as the door and air inlet. The upper rim of the liner has three raised pot rests.

The *Maendeleo* 1 stove is made completely from available materials at a minimum cost. It has no metal parts such as grates, heating plates or hinged doors.

The stove is constructed upon a foundation made from local materials. A large flat stone is sunk into the foundation and the ceramic liner is positioned atop of it. Mud/clay walls are then built around the sides of the liner, leaving a raised platform in front of the door. Called the tongue, this platform supports sticks being fed into the fire and allows air to move underneath them.

Advantages of the *Maendeleo* 1 Stove

The *Maendeleo* 1 Stove is about 30% efficient when properly built and used. The insulated firebox allows the fire to burn at a steady rate without being blown by the wind. Furthermore, it makes use of convected heat which is otherwise wasted by open fires to direct rising hot gases up the sides of the cooking vessel, conducting some of this heat into it.

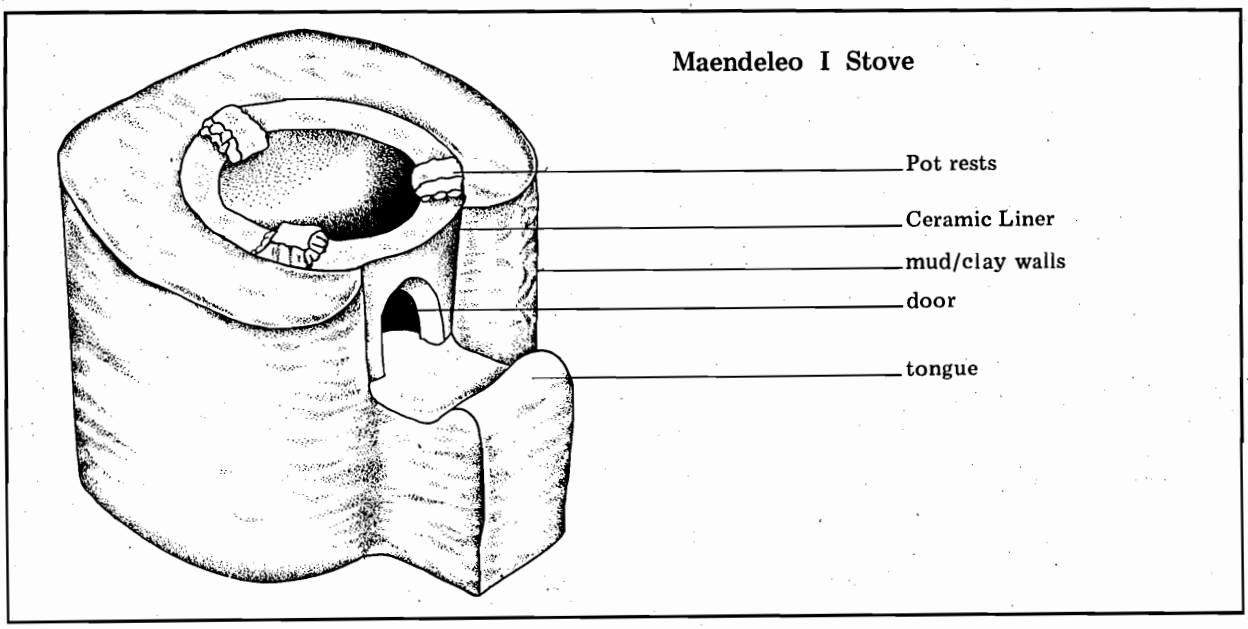
Besides conserving fuelwood, the stove has other advantages. As mentioned above, it costs almost as little as the three-stone fire to construct. Like the open fire, it burns any type of fuel (even grass and dung) and is easy to manage. The *Maendeleo* 1 Stove also reduces smoke in the kitchen and prevents children and old people from getting burned.

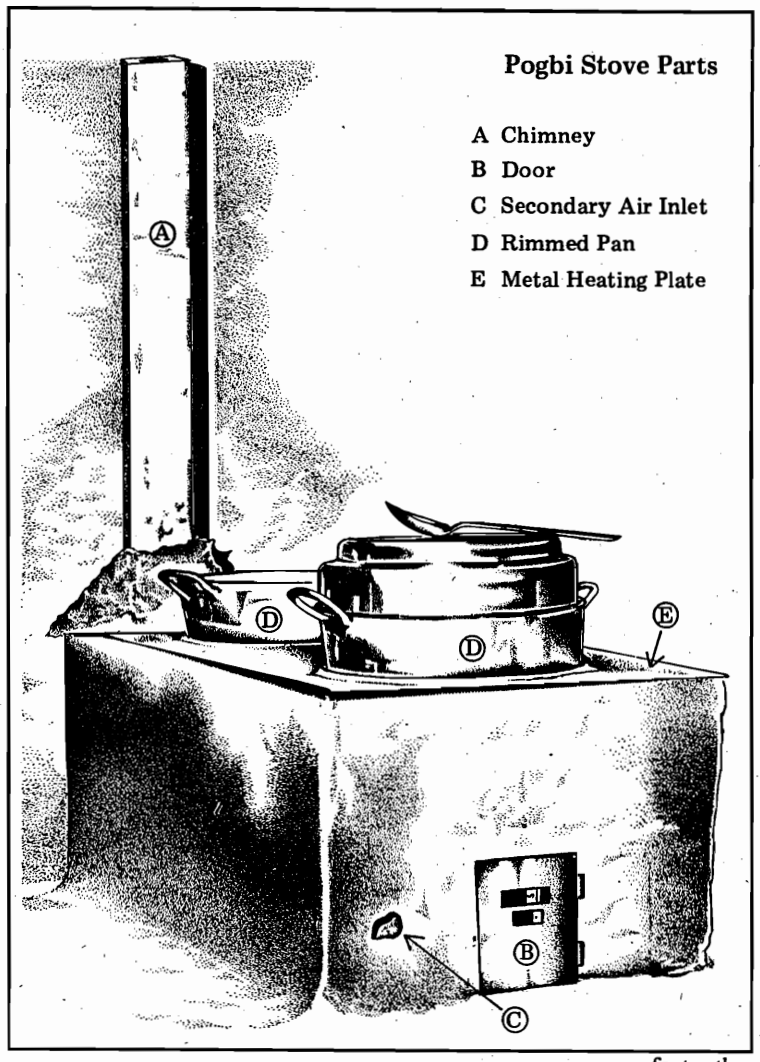
Distribution

Women's groups in Kiambu, Kisii, Meru and Murang'a had built 2,500 of these stoves by August 1986. As of January 1987, 6,000 stoves had been built in the same areas. There is a particular demand for the stove in areas such as Kiambu where women now have to buy fuelwood and hence see the need to conserve it. By December 1987 it is estimated that there will be approximately 20,000 stoves in use.

The *Maendeleo ya Wanawake*/GTZ Stove Programme has been training women's group representatives, local Government Community Development Officers, as well as Ministry of Agriculture Technical Assistants and Home Economics Officers, to teach and supervise stove building. Typically, women build stoves in their own houses under the supervision of trainers.

Ceramic liners for the stoves are made centrally by Clay Works in Nairobi and also by local potters or production centres in Kisii, Meru and Murang'a. The demand for the stove is great in all parts of Kenya, but the project aims for a self-sustainable production and supply system in the pilot districts before moving to new areas.





The Pogbi Stove

The Pogbi stove is an energy conserving wood burning stove developed by the Bellerive Foundation and available at their workshops in Ruiru. It was specifically designed for areas such as Central Province which suffer from fuelwood shortages. Also based on a stove used in Burkina Faso, the Pogbi stove has a tested and proven design that decreases firewood consumption and improves kitchen health conditions.

The stove body is made from a clay/straw mix with a metal grate and heating plate. A hinged metal door allows for the loading of wood and entry of primary air, while an additional hole allows preheated secondary air to enter the fire. Baffles direct air in such a way that it moves around the first pan and transfers its heat to the pan in the second chamber on its way out the chimney. The chimney is made of moulded clay segments which may be extended out of the kitchen with sheet metal pipes.

The heating plate, made from long-lasting 3 mm sheet metal, has round openings for two *sufurias* to sit inside the stove chambers. Although the rimmed pans supplied with the stove work best, the stove can accept various conventional *sufurias*.

The diagram on page 54 shows the draught flow through the store during operation. Split, dried wood is ignited atop the grate and once it is burning the door is closed. Primary and secondary air channels insure complete combustion of volatile gases inside the firebox. The first pan is heated mostly by radiated heat from the firebox, while the second pan receives most of its heat from convection currents.

Trained artisans build Pogbi stoves at the Ruiru site outside Nairobi. They use specially prepared clay reinforced with dried grass which increases the strength of the stove structure. Moulds are used to shape the stove walls, firebox and air ducts.

The Pogbi stove is significantly more expensive than the *Maendeleo* stoves. However, its construction and design make it more efficient than *Maendeleo* stoves. It is also likely to last longer. Ruiru stove builders will install the stove in the buyer's kitchen and give instructions on the stove's operation and maintenance. The Pogbi stove is the most efficient wood burning domestic stove presently available for sale in Kenya.

The Nandi Clay Stove

The Nandi clay stove is an example of a stove that has spread to thousands of homes because of its advantages over previous cooking fires.

The stove was introduced in 1956 as an improvement of the traditional sunken fireplace. At that time, women frequently brought children to dispensaries who had been burned by falling into the fireplace. In fact, the problem was so widespread that it was common to see burned children in hospital wards. There was thus an outcry against the sunken fireplace which prompted the colonial Health Department authorities to introduce a modified stove.

The original design for the improved Nandi stove was by Mr. A.T. Matson and Jamaldin Esmail, health department workers in Nandi District. The stove was spread to local health centres and *kokwets* (homesteads) by Mr. Matson's wife and the *Maendeleo ya Wanawake* organization.

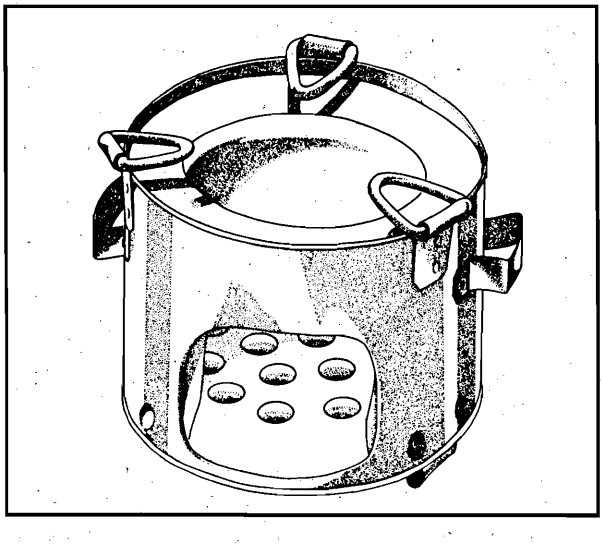
The stove is built by arranging several large stones or bricks in a box shape, often on a raised platform. Smaller stones are then packed around them for support and the stones are then covered with a mud/sand mixture, leaving holes for two pots. When dry, this structure is smeared with a mud/dung/sand mixture. The original design had a chimney and a hollow space for keeping food warm.

Women adapted the original stove design to suit their own needs, changing the stove sizes, the number of cooking holes, or by not building the chimney. During the early 1960's, the stove became quite popular among women. Even after the organizations which were supporting stove building were no longer functional, women continued building Nandi clay stoves. Now, over twenty-five years later, most *kokwets* in the northern part of Nandi District use Nandi stoves.

Table 3.11 Comparative Energy Efficiencies of Various Cooking Tools

TOOL	EFFICIENCY	PORTABLE?
Three stone fire	5-15%	Yes
Improved three stone fire	15-20%	Yes
Maendeleo stove	25-30%	No
Pogbi stove	30-35%	No
Kuni Mbili	25-30%	Yes

The main advantage of the Nandi stove is that it prevents children from getting burned in the kitchen. However, the stove also allows women to conveniently cook more than one dish at a time. Furthermore, the enclosed firebox probably aids firewood conservation. Although Nandi stoves have not been *tested* for efficiency, women report that the stoves consume less firewood than the traditional open fire.



Kuni Mbili

Kuni Mbili (above), developed by KREDP, is a portable stove which cooks food efficiently with firewood. Some of the new *Kuni Mbili* models can cook with firewood or charcoal. Preliminary tests indicate that the *Kuni Mbili* has a 30% laboratory efficiency, though field tests suggest the actual use efficiency will be about 25%. Originally developed by Max Kinyanjui, the stove is similar in design to the KCJ but adapted primarily for wood instead of charcoal. Although the stove was still being tested and refined as of December 1986, artisans had already begun to market it.

Bellerive Community Stoves

Institutions such as schools, colleges, hospitals, and prisons buy cut fuelwood and charcoal in large volumes for preparing meals. Great amounts of energy and money are wasted cooking meals over open fires or old inefficient stoves. Kenyan institutions can save much money and wood by adopting sturdy, long-lasting, energy-saving stoves for their kitchens.

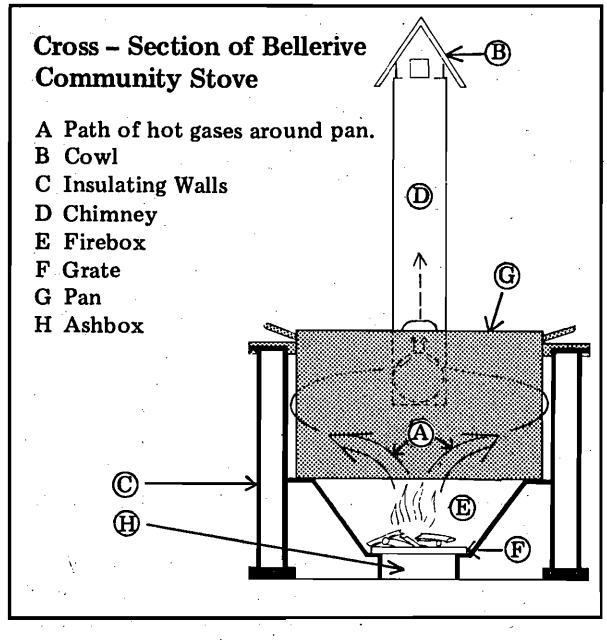
Bellerive Community Stoves are examples of cheaply available stoves which save a great amount of wood energy. Savings in woodfuel purchases enable institutional stoves to pay for themselves within six months to a year.

Mr. Wiclaw Micuta (nicknamed "*Bwana Jiko* ") and Mr. Emil Haas (nicknamed "*Mzee Jiko* ") attended the 1981 UN Renewable Energy Conference as stove experts. After the conference, they initiated a local wood stove programme, the Bellerive/UNEP Fuel Saving Project, which was started in Ruiru. The project goals were to design and develop fuel-efficient stoves and to train local artisans to build them. Under the management of Mrs Sophia Kiarie, the Ruiru Centre has sold hundreds of household and institutional stoves since 1983.

Realising that there would be a demand for energy-saving stoves in kitchens that cook meals for large numbers of people, the Ruiru Centre concentrated on institutional stove designs. In May 1985, they launched the *Bellerive Community Stove*, and since then their artisans have built and installed stoves in schools and colleges all over Kenya.

Description

Bellerive Community Stoves are available in several different sizes (50, 100, 150 and 200 litres) and made from either clay or brickwork and sheet metal. All of them are cylindrical and are topped by a ring-shaped iron plate and a metal chimney. This section describes the 200-litre brickwork/sheet metal stove.



Long lasting and sturdy, the stove will cut fuelwood use by at least 50% if properly used. The cylinder-shaped outer wall is built from burnt bricks and protected by a galvanised metal sheet. Inside the wall is a brick-lined conical *firebox* and a space in which the cooking pan sits. A cast iron *grate* is located below the firebox.

The *door* is a closeable metal sheet with inlets for both primary and secondary air. Wood must be cut in order to fit into the opening and still allow the door to be closed during stove operation.

A ring-shaped metal plate located on top of the walls serves to enclose the stove and support the rim of the cooking pan.

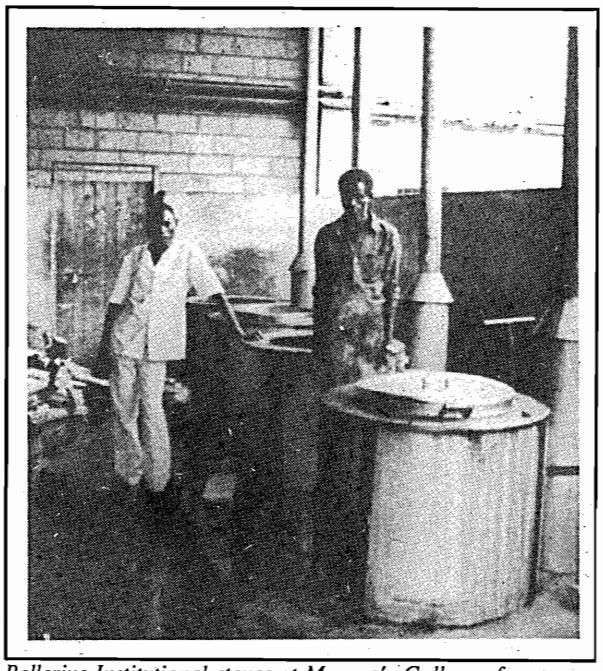
The stove's *chimney* is connected to a 14 cm diameter sheet metal pipe which conducts smoke out of the kitchen. The chimney's opening inside the stove is located so that hot gases must pass around the pan before exiting the stove.

All Bellerive Community Stoves are supplied with stainless steel cooking pans. These pans have an upper rim which allows most of the pan to sit inside the firebox area.

Operation

These stoves require that cooks learn simple operation procedures. The fire in the stove should be carefully controlled and fed with chopped dry wood. Once food has been brought to a boil, wood need not be added to the fire as the insulated cylinder walls retain heat very well. Meals such as *githeri* should be pre-treated by pre-soaking maize and beans before cooking (this can save energy with any stove). Following the operating instructions given during installation of the stove will result in large savings in woodfuel use.

Bellerive stoves efficiently utilise heat produced by the fire. The pan absorbs radiation optimally because it is sitting *inside the stove* at the correct distance from the fire. Instead of losing heat from the sides of the pan to the outside by radiation, the pan gains heat by convection from hot gases which pass around its sides (see figure). The draught through the fire, made possible by the air openings and the chimney, enables wood to burn completely. Even after the fire has burned down, the pan gains heat radiated from the heat-retaining firebox.



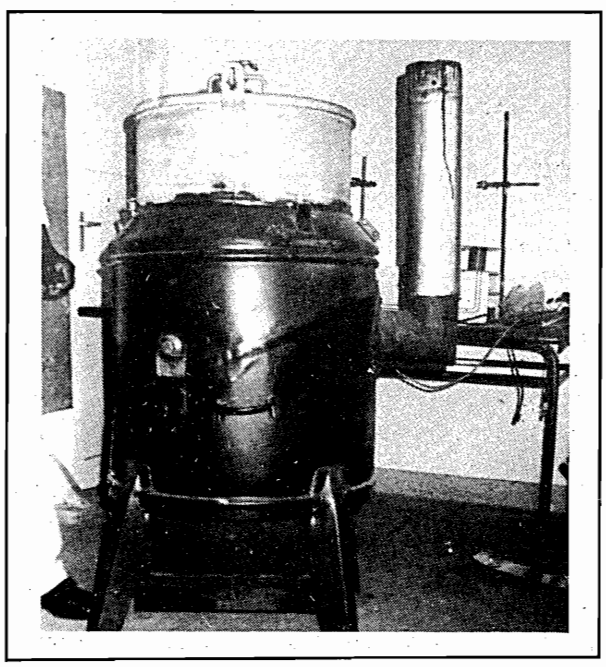
Bellerive Institutional stoves at Murang'a College of Technology.

Distribution

The money-saving advantages of Bellerive Community Stoves have been demonstrated by the rapid rate at which insitutions are demanding them. During the twenty months after it was launched, more than 160 Bellerive stoves were installed in institutions all over Kenya. Most of the stoves have been built in Central province, but many are also found as far away as Mombasa and Kisumu. Kirinyaga Secondary School, Machakos Teachers Training College, Kabarak High School and Pangani Girls Hostel are all examples of institutions now using these improved stoves.

The Bellerive Fuel Saving Project has recognised that improved stove designs alone will not ensure woodfuel savings. Therefore, it has also concentrated on training local artisans to build efficient stoves and training local cooks to use the stoves. More than twenty stove builders have been trained at Ruiru, and some of them are now employed building stoves in other parts of Kenya. A stove similar to the Bellerive is now built in Murang'a by Ruiru-trained artisans.

Furthermore, during stove installations, Bellerive *fundis* spend three days teaching cooks how to use the stoves properly. They also return to maintain and inspect the stoves several times in the months after they have installed them to ensure optimal use.



Alfa Laval Institutional stove.
Locally made, these stoves are used in hundreds of schools and hospitals across the country.

Traditional charcoal mound kiln.

Improving Charcoal Production Efficiency

Charcoal is the most important urban cooking fuel. It is also an important fuel for the cement, lime and brick burning industries. During 1982 about 1.4 million tonnes of charcoal were burned in Kenya to supply about 6% of the nation's final energy demand.

Almost all of the charcoal in Kenya is made in traditional kilns. Because of the low efficiency of traditional kilning methods, about four units of wood energy are used to make one unit of charcoal energy. Less than a quarter of the energy in the wood is available in the final charcoal product.

By improving traditional kilning methods and technologies, Kenya can save very many trees.

The Charcoal Industry

About 50,000 people are employed making charcoal. A typical charcoal-maker produces 15 bags a week in traditional earth-mound or pit kilns. Because the traditional charcoal-making process takes time to master, these kilns require skilled and experienced operators.

Charcoal is transported from up-country production areas to urban centres. A bag of charcoal used in Mombasa might have come from Hola, while a bag of charcoal used in Nairobi might have come from Isiolo. Most of the charcoal in Kenya is made from trees in semi-arid rangelands.

The charcoal industry provides benefits for people in rural and urban areas. Charcoal-makers, sellers, and transporters are employed by the charcoal industry. The industry brings cash income to rural areas and fuel to urban areas. Charcoal saves foreign exchange because it is a substitute for imported paraffin and gas.

The Charcoal Product

Carbonisation of any biomass drives off the hydrogen and oxygen from the material and leaves a charcoal product that is almost pure carbon. Charcoal is composed of carbon (90% by weight), water (usually about 5% moisture content) and ash which is left behind after burning. Charcoal made from wood usually has an ash content of about 4% while charcoal made from other biomass (bark, coffee husks, peat, etc) may have an ash content as high as 10% to 20%.

The energy value of charcoal (5% moisture content) is about 32 MJ/kg. This is two times the value of energy in air dry wood and accounts for the

popularity of charcoal in urban areas.

The weight per unit volume of charcoal depends upon the density of the wood from which it was made. Dense hardwoods such as mangrove produce charcoal that weighs 55 kg per bag while very soft woods produce charcoal that weighs less than 25 kg per bag. Charcoal from rangeland trees such as *Acacia* weighs about 35 kg per bag.

The Charcoal Making Process

Raw Materials

Charcoal in Kenya is made almost exclusively from wood. Dense woods are preferred because they produce charcoal which is clean, long-burning and resitant to breakage. Charcoal made from less dense woods lights easily but tends to crumble and produce a lot of *fines* (particles of charcoal, too small to use in the *jiko*). Experienced charcoal makers choose wood in good condition, splitting and chopping it so that it stacks easily. Wood should always be as dry as possible before kilning.

Other materials that have been used to make charcoal are coffee husks, peat, coconut shells, sawdust and straw. Sri Lanka exports charcoal made from coconut shells. In Kenya, the Kenya Planters Coffee Union makes *Kahawa Charcoal* from coffee husks (see box page 71). In general, materials other than wood produce charcoal with a high ash content and a high percentage of fines. A special process called *binding* is required to press *fines* into *briquettes*, lumps of pressed charcoal, before they can be used.

Carbonisation

Charcoal is made by the *carbonisation* of biomass. During carbonisation, a certain amount of biomass, called a *charge*, is heated in a container without oxygen and chemically reduced to produce the high carbon charcoal product. Carbonisation is carried out by two general methods: the *kiln method* or the *retort method.*

The *kiln method* burns part of the charge inside the kiln in order to produce the heat for carbonisation. This is the method used to produce all of the charcoal in Kenya.

The *retort method* converts the charge to charcoal inside a closed chamber with the heat coming from *outside* the chamber. Retorts allow the collection of gaseous and liquid by-products of carbonisation.

Stages of Carbonisation

There are four stages in the carbonisation process. The first two stages occur in the presence of oxygen, but its supply is limited and completely stopped during the last two stages.

Combustion (this stage does not apply to the retort method). Kindling material and part of the charge are burned inside the kiln in the presence of oxygen to produce heat that initiates carbonisation. The temperature rises rapidly as the fire is allowed to burn for about an hour, and then the air supply is reduced. The temeprature drops from over 400°C to below 150°C.

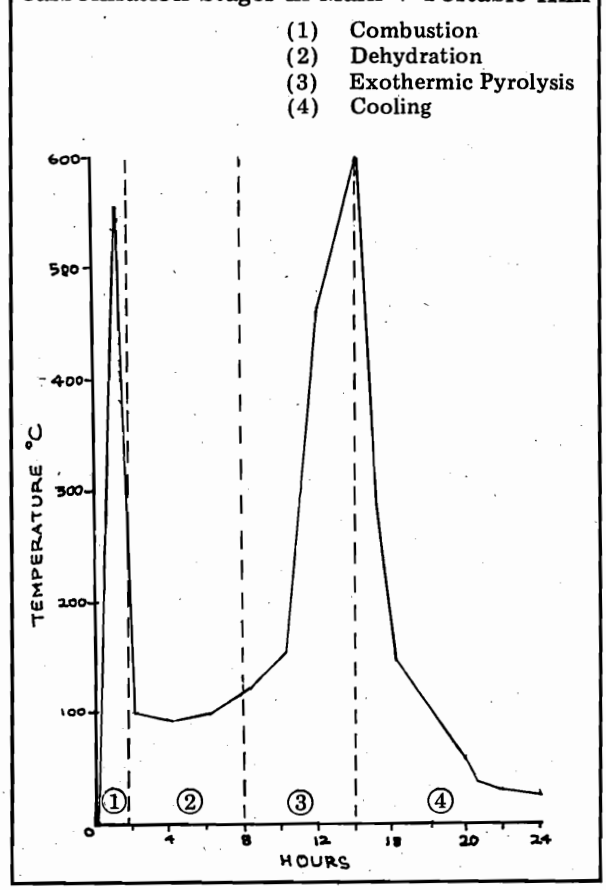
Drying. During drying, water is driven from the wood. The wetter the wood, the longer this process takes and the more energy consumed. Wood with a high moisture content can cause this stage to last more than twelve hours.

The kiln temperature stays around 110°C while water is expelled from pores in the wood. The white smoke given off at this time is mostly water vapour. Later, the temperature slowly rises to 270°C while water is driven from cellular structures in the wood. White smoke changes colour to a dark blue at the end of the drying stage, and the charcoal maker then further reduces the air supply.

Exothermic pyrolysis. The temperature begins to rise rapidly above 280°C. It is during this stage that the exothermic process called *pyrolysis* occurs. Pyrolysis is the chemical breakdown of wood (or any biomass) at high temperature in the absence of oxygen.

The air supply is limited during this stage as the pyrolysis reaction produces its own heat. The ideal carbonisation temperature range of between 400 and 500°C can give over 90% carbon yields. Dark smoke with a heavy smell is given off during pyrolysis. This smoke contains volatile gases (including hydrogen, carbon monoxide and methane) and vapours (methyl alcohol, acetic acid and tars). By the end of this stage, the structure of wood has broken down, and it loses much of its volume while becoming charcoal.

Carbonisation Stages in Mark V Portable Kiln



Cooling. During the cooling stage, kilns are sealed completely to prevent any air from entering. If air is allowed to enter, charcoal will ignite spontaneously. The rate at which charcoal cools depends on the type of kiln or retort used. Usually, about 24 hours after starting the process the kiln is opened, at which time water may be poured on the charcoal to prevent further combustion.

Charcoal is then allowed to *season* for at least a day, during which time it absorbs oxygen. Seasoning charcoal should be checked periodically to make sure it does not ignite.

Energy Losses in Charcoal Production

In the Kilning Process

Charcoal contains concentrated energy and is therefore preferred by urban people. Much energy is used to make charcoal from the less concentrated energy in wood. It takes between six and nine tonnes of wood to make one tonne of charcoal using traditional kilning methods. In energy terms, a tonne of charcoal contains about one quarter of the energy originally contained in the six to nine tonnes of wood from which it was made. Three quarters of the energy in the wood is either used as heat during the charcoal making process or escapes as volatile gases, liquids and tar.

Fines

As mentioned before, during kilning (especially of less dense woods) a lot of unusable fines are produced. As much as 30% of the charcoal product of one charge may be fines. These fines are left at the kilning site.

Furthermore, during transport, vibrations of the moving vehicle and handling at the market site cause bagged charcoal to break and form more fines. The farther the journey, the more charcoal is broken into fines. Charcoal sold by the bag in urban areas typically has at least 5% fines.

By-products

During kilning, by-products of the pyrolysis reaction are lost as smoke or liquid. In other countries, these by-products which include methyl alcohol, acetic acid and creosote, have been collected and sold or burned for process heat. However, now that the petroleum industry makes most of these chemicals quite cheaply, it is too expensive to economically collect pyrolysis by-products. A small-scale charcoal maker would not be able to afford the distillation equipment (but it is possible to have a small drop pan to collect tar and other liquid by-products). By-products which could be collected from 1000 kg of air-dry wood during carbonisation are listed below with their uses:

Table 3.12: Carbonisation By-products from 1000 kg Air-Dry Wood

PRODUCT	AMOUNT	USES
Producer Gas (Wood gas)	115 m^3	Burned to produce process heat
Pyroligneous Acid (Solution of Water Soluble Products)		
Methyl alcohol	14 l	Industrial solvent
Acetic acid	53 l	Textile industry, converted to acetone
Esters	8 l	
Acetone	3 l	Industrial solvent
Wood Tars (Water Insoluble Products)		
Wood oil	76 l	
Creosote oil	12 l	Wood preservation
Pitch	30 kg	Road making

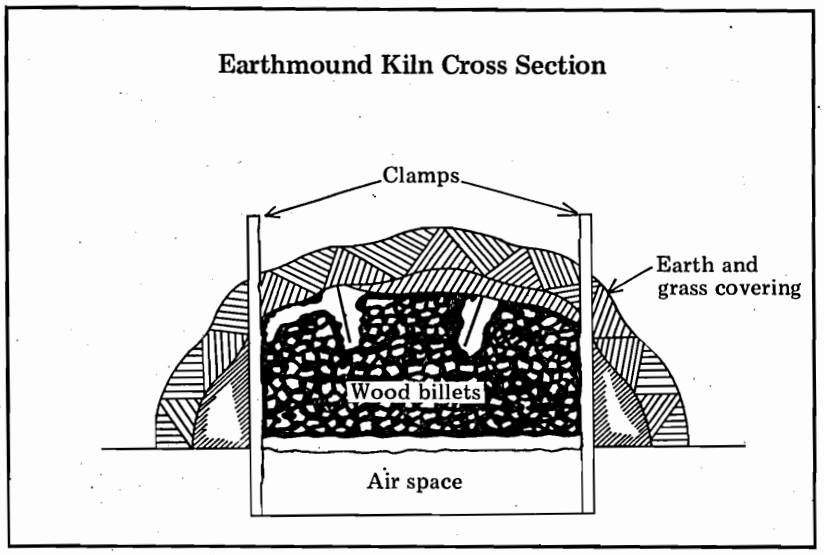
Source: Data from tests with Lambiotte retort. Kionga-Kamau,1981.

Charcoal Making Technologies

Earthmound and Pit Kilns

A vast majority of Kenya's charcoal is produced using traditional methods in earthmound and pit kilns. In rural areas, charcoal makers are often seen at work near smoking earthmound kilns.

Earthmound kilns are constructed by carefully piling cut wood, and then covering it with leaves, sand and soil. Spaces are left for air inlets, and at least one chimney is built for smoke to escape. Pit kilns are similar to earthmound kilns, but the wood is arranged in a rectangular hole and air is allowed to pass underneath the wood. Wood in pit kilns and earthmound kilns is ignited while air holes are open. The charcoal-maker watches the smoke from the fire, compeltely closing the air holes with earth when he sees the dark smoke that signals the start of pyrolysis.



Earthmound and pit kilns waste much energy. They have efficiencies of between 8 - 15% depending on the skills of the operator and the moisture content of the wood. Operation of traditional kilns requires much practical knowledge, and for this reason full-time, experienced charcoal-makers produce more charcoal per volume of wood than the inexperienced.

Although traditional kilns are not very efficient and produce a product that is often mixed with soil and stones, they have several advantages over other types of kilns. They require no money to build and they can be built anywhere. Whenever the charcoal-maker fells a tree, he can build a kiln. In addition, earthmound and pit kilns fit the informal status of the charcoal-making occupation.

Permanent kilns

Permanent types of kilns have evolved from traditional kilns because they give a better control of the charcoal production process and improved yields. Because they do not allow earth, stones or other foreign matter to mix with the charcoal, these kilns are faster, more efficient and they produce a cleaner product. Permanent kilns are also easier to operate because they have fixed, adjustable air holes and chimneys and because they are easily fired, loaded and unloaded. Near plantations and forest thinning operations, many kilns can be operated at onee, increasing the profitability of kilning. Many kilns operating together are called a *battery* of kilns. Permanent kilns can be divided into two general types: *fixed kilns* and *portable kilns.*

Fixed kilns.

These are closed chambers made from brick and mud/cement with a loading and unloading door. They have chimneys and closeable air holes around their base. Wood is stacked inside the kiln chamber in an arrangement that depends on the type of kiln. The operator lights a fire inside the kiln, closes the door, and watches the smoke escaping from the chimneys. As the carbonisation process proceeds, holes are closed one by one until the kiln is sealed. The charcoal is then allowed to cool. Before unloading the kiln, water may be poured on the charcoal to prevent it from igniting.

Because fixed kilns cannot be moved, wood must be carried to them. Thus, for an economical operation, they should be built near a permanent source of wood such as a regularly thinned forest, a plantation or a sawmill. Fixed kilns are often very large in size.

Portable kilns

Portable kilns are usually made out of metal. One type has a cylinder-shaped body with a conical roof which can be taken apart and carried in several pieces. Air moves through portable kilns by means of metal air holes and chimneys which are attached at the base of the kiln.

Portable kilns are carried to the site, put together and loaded. The first conical section is positioned on a flat, clear space, and the chimneys and air inlets are arranged equidistantly beneath the base. Wood is then stacked inside the kiln and the other sections and the lids are assembled. The wood charge is lit by igniting inflammable materials in the centre of the kiln. Portable kilns are operated in much the same way as fixed kilns. After the charcoal has cooled, the kiln is taken apart and the charcoal is unloaded.

Portable kilns are carried to sites where wood is available. If, for example, land is being cleared, portable kilns can be used to make charcoal at the site. Because they must be transportable, portable kilns are limited to a maximum volume of about 3 to 4 m^3 and, because of their relative bulk, it is uneconomical to move them frequently.

Example 1: Kilns on a Woodfuel Plantation: The Mark V Kiln and the Half Orange Kiln

Two charcoal kilns were tested by the GTZ Special Energy Programme and the Muka Mukuu Co-operative Society near Ol Donyo Sabuk in Machakos. The aims of the test were to discover whether a charcoal producing plantation would be economical, and if so, which type of charcoal production would be most feasible. The Mark V portable kiln and the Half Orange kiln were compared on a 722 ha sisal plantation which had been overgrown by *acacia* trees.

The Half Orange is a hemispherically shaped *fixed* brick kiln first developed in South America. The Mark V is a *portable* metal kiln made locally in Nairobi by Haartz and Bell.

Production of charcoal in Muka Mukuu was found to be economical for several reasons. Demand for charcoal in nearby urban areas such as Thika and Nairobi is quite high, and production of charcoal in such nearby sites as Muka Mukuu could reduce transport costs of the industry. Furthermore, by producing sustainable yields of charcoal on a managed energy plantation, the pressure on forest reserves in semi-arid areas could be reduced.

Table 3.13 compares the performance of the two kilns. The Half Orange kiln has a larger charging capacity and a higher efficiency than the Mark V kiln, and thus produces charcoal much more cheaply per bag.

Table 3.13: The Mark V Kiln vs. Half Orange Kiln at Muka Mukuu, Machakos

FEATURE	MARK V	HALF ORANGE
Charging capacity	7 rm	12.5 rm
Weight of fuelwood input (15% Moisture Content)	460 kg/rm	460 kg/rm
Bulk density of charcoal product	200 kg/rm	250 kg/rm
Charcoal yield (not including fines)	3 rm	6.5 rm
Efficiency (by weight)	19%	28%
Cost per bag of charcoal* (KShs/bag)	27.3	19.5
Kilning time	26 hours	45 hours

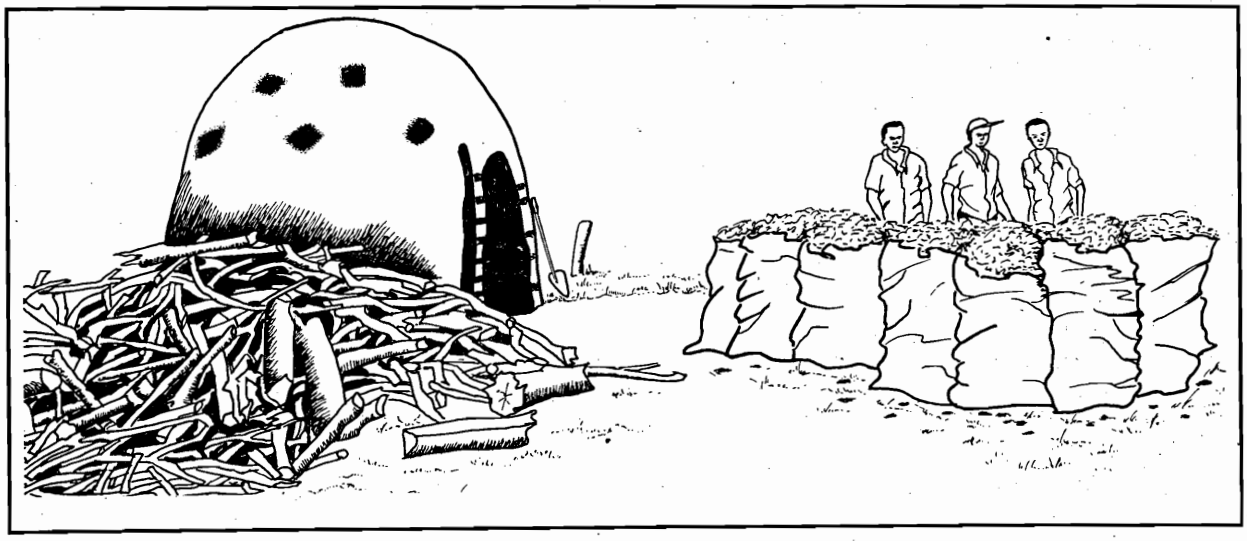
* 1984 Kenya Shillings
Source: Charcoal Production and Research Activities Within the Special Energy Programme Kenya, GTZ, Nairobi 1984.

Although the Mark V kiln is faster and transportable, these advantages are not found to be major factors at Muka Mukuu (trees are readily available on the plantation). Therefore, the Half Orange Kiln was chosen as the more economically viable alternative at Muka Mukuu. The Mark V, however, has been profitably used to produce charcoal from pruned coffee branches by Kenya Canners in Thika.

The Half Orange kiln can be built from clay brick (as produced by Clayworks outside Nairobi) or from bricks made at the site (if a suitable material is available). Profitable production of charcoal from the kiln requires that fuelwood be split and dried, and that the kiln be properly operated.

The Half Orange kiln is now widely used in South America, and this can be attributed to its several advantages. It can be cheaply built from local materials such as clay, sand and charcoal ash. It has a lifetime of over ten years. It is simple to operate once the charcoal maker has been instructed. Most importantly, it gives high yields of charcoal and, when operated in batteries, it can give quick returns on the initial investment.

Demonstration Half Orange kilns (below) can be found at Muka Mukuu and at the Agroforestry Centres all over Kenya (see Appendix). The Ministry of Energy and Regional Development also has information on these kilns.



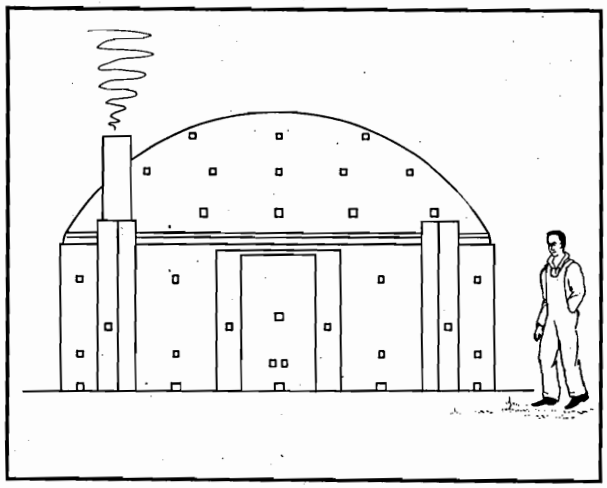
Example 2 :East African Tannin Extract Company's "Beehive" Kilns

In Eldoret, the East African Tannin Extract Company (EATEC) uses 14 large beehive brick kilns. Staffed by trained and experienced people, the kilns produce good quality charcoal at a high recovery efficiency (about 25-32% from oven dry wood). The kilns were constructed for carbonising debarked wattle wood so that it could be transported and sold profitably. The company uses wattle bark to extract tannin, a valuable leather curing product.

Typically about 72 tonnes of debarked wattle are loaded (charged) into each of the brick kilns. The total carbonisation time is thirteen days: one day for loading, three days for burning, eight days for cooling the kiln and one day for unloading. An average yield from 72 tonnes of wood is 21 tonnes (600 bags) of charcoal

Each beehive-shaped kiln is 12 m long, 5 m wide with a 3 m roof. There is an opening for charging and discharging and side vents which are closed as carbonisation proceeds. A chimney is located at the far side of the kiln opposite the door (see figure below).

The brick kilns are located on EATEC's extensive wattle plantations and therefore wood does not have to be carried very far to be loaded into the kilns. EATEC is Kenya's only large-scale charcoal kilning company.



Beehive type permanent kiln.

Permanent kilns are easier to operate than pit and mound kilns. They are also more efficient, particularly when the kilning operator takes care to split and dry wood before kilning. Kilns are operated in batteries in appropriate areas to produce charcoal in volume.

Kilns are quite expensive to build. A typical charcoal-maker could not afford to buy a steel kiln, nor would it be in his interest to build a fixed kiln. Permanent kilns are most profitable for such operations as fuelwood plantations, land clearing projects, sawmills and organised groups of charcoal-makers.

Retorts

Retorts are metal or brick ovens inside which the biomass charge is heated in the absence of oxygen. The heat used to initiate the pyrolysis reaction comes from *outside* the oven. None of the charge itself is combusted inside the retort's oven.

Retorts are sealed and fired from outside the oven. Because the temperature of carbonisation can be carefully controlled from outside the oven, retorts have very high yields. The efficiency of retorts varies between 28 and 38%.

In addition, retorts allow the collection of the volatile gases and liquid by-products of carbonisation. Producer gas generated during pyrolysis is often used as a fuel to heat the oven.

Retorts are very expensive. They require both capital and technical expertise to construct and operate. In Kenya, only a very large centralised operation would be able to build, manage and maintain a retort. It is also unlikely that collected by-products could presently compete with the same products produced by petroleum refineries.

Practical Charcoal Production Improvements

The previous sections have described how the charcoal industry presently wastes energy. About $^1/_3$ of all wood cut in Kenya is used to make charcoal. Therefore, one of the most promising options for reducing wood demand is to increase charcoal making efficiencies. Several strategies to improve this country's wood to charcoal conversion efficiency are listed below. Successful improvements must involve both small-scale charcoal producers as well as larger industries.

Improving Traditional Earthmound and Pit Kilns

The task of improving charcoal making efficiencies must start in the traditional kilns where most of the charcoal in Kenya is made.

Charcoal makers should kiln only *DRY WOOD*. Wood should be split while it is still green to reduce its drying time. At least two months is best, but wood dried for only three weeks will kiln better than green wood. Dry wood carbonises faster and gives a much higher yield than wet wood.

Charcoal makers should build and manage their earthmound and pit kilns carefully. Poorly built kilns give very low yields. Proper stacking of the wood and careful control of the kiln will increase charcoal yields.

Example : The Casamance Kiln

The Casamance is an example of one of the most promising improved earth kilning methods. Because its simplicity and low cost makes it easily adoptable by low-income charcoal producers, the kiln has been widely used in Senegal for many years (and has recently been introduced in Mozambique).

Construction. Essentially, the Casamance kiln is a very carefully constructed earth kiln with optimally located air inlets. The kiln is constructed by arranging a platform of wood billets radially around a centre post (see figure below). Wood is stacked atop the platform, placing large pieces close to the centre post, until a hemispherically shaped mound about 1.5m high is built up. Enough space is left between the wood billets so that air can circulate during firing.

The kiln is first covered with grass or turf, to prevent earth from falling between the stacked wood, and then a layer of earth (20-30 cm deep) is spread on top of the grass. After the kiln is covered, four to six equally-spaced *air inlet channels* (75 cm long, 30 cm wide) are dug out at the base of the kiln.

Operation The kiln is lit by removing the centre post and dropping inflammable materials into the remaining hole. Embers of burning charcoal are then dropped atop these materials. Fire ignites inside the kiln and becomes established within half an hour. As the fire spreads it violently throws hot gases and dust out the centre post hole, and, after an hour, the top part of the kiln starts to collapse. This indicates that carbonisation has started. The operator then closes the hole with billets of wood, grass and earth. He also punches several air outlet holes into the sides of the mound.

After four to six hours, the entire top of the kiln sinks because the wood in the middle part of the kiln has lost its volume. The charcoal maker fills any holes formed at this critical time with soil, preventing charcoal inside the kiln from bursting into flames. A second inspection of the kiln is made between 12 and 18 hours to again seal cracks with soil.

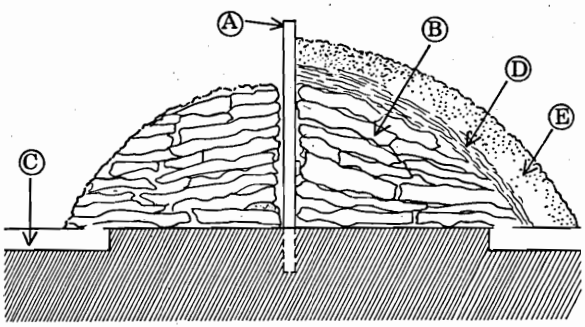
When the operator notices that carbonisation is complete after 3-4 days (there is a reduction of smoke), he seals all vents and cracks in the kiln. It is allowed to cool for up to four days, and then carefully opened by removing soil from the base and walls. Charcoal is spread with a rake and allowed to season for at least 24 hours before bagging.

Advantages of the Casamance Kiln The most important advantage of the Casamance kiln is that it yields more charcoal than pit and mound kilns. Because of better control over the kiln's air flow, it gives yields of between 20 and 30%. This is typically two times higher than traditional kilns. Also, the Casamance kiln has a shorter production cycle than similarly sized pit or mound kilns.

Unlike permanent kilns, the Casamance kiln costs nothing to build. There is no need to transport wood to the kiln (or the kiln to the wood). In addition, wood need not be split when using this kiln.

Finally, it has been shown that a distilling chimney can be attached to the Casamance kiln, enabling collection of some carbonisation by-products. In some areas where there is a local need for such products as wood tars or creosote, this could be quite useful.

Casamance Kiln Cross Section



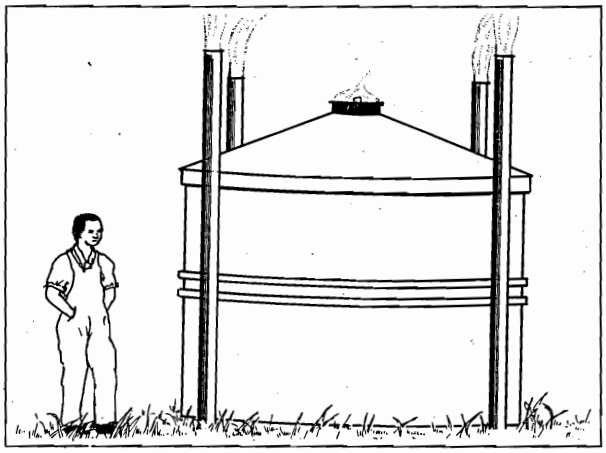
A Centre Post
B Wood billets
C Air Inlets
D Grass/turf covering
E Earth covering

Adopting Efficient Permanent Kilns

Pilot projects have demonstrated that permanent kilns could be economical at certain sites in Kenya (see page 68). Much success has been achieved with permanent kilns in Uganda. Energy-efficient permanent kilns could be introduced by the government, private industry or charcoal-making co-operatives.

Fixed kilns are often used to make charcoal at appropriate sites. Fuel plantations near fixed kilns in Brazil supply wood to produce charcoal for that country's iron industry. Fixed kilns like those at Muka Mukuu (Machakos) and Eldoret could be built near forests, kilning wood from thinnings and fellings, or near sawmills kilning waste wood.

Portable kilns like the Mark V have been used profitably in small and medium sized charcoal operations. The forest department in Uganda has supported the use of transportable kilns in refining and enrichment of tropical high forests such as Mabira Forest. Portable kilns used in land clearing operations can also make valuable use of cleared trees and bush.



Mark V portable charcoal kiln.

Making Use of Charcoal Fines

As much as $^1/_3$ of the charcoal kilned locally is lost as fines during production and transport. Fines contain as much energy as uncrumbled charcoal, but are not sold to consumers because they cannot be burned in *jikos*. There are two ways in which fines can be profitably used:

-- Charcoal fines are burned directly in industry. Processes for making lime, cement and bricks can use charcoal fines. Charcoal-makers could thus bag fines and sell them to transporters who could take them to industry.

-- They may also be made into *briquettes*. Women in Nairobi markets presently collect charcoal fines, mix them with mud and sell them as briquettes. Charcoal fines are mixed with a substance called *binder* that holds them together. The fines and binder are pressed into briquettes and dried. These are sold in the same way as charcoal.

Making Charcoal from Waste Biomass

Certain types of waste biomass are produced in a high enough volume to consider using them as a raw material for making charcoal. This is an area where industry can play a valuable role by collecting biomass wastes centrally and processing them into charcoal. As mentioned before, Sri Lanka exports a high quality charcoal made from coconut shells.

Example: Coffee Husk Briquetting at KPCU

Thirty five thousand tonnes of coffee husks and parchment are available each year in Dandora and Kirinyaga as waste biomass from the coffee industry. In Dandora, the Kenya Planter's Co-operative Union (KPCU) has developed a way to use some of this waste biomass to make charcoal briquettes which are profitably sold. There are four steps in KPCU's charcoal briquette production process:

Carbonisation takes place in modified concrete pit kilns. Coffee husks are carbonised layer by layer until the concrete pit is full of charcoal, using kilning methods which remove tar and ensure complete carbonisation of the product.

Braiding involves wetting of the charcoal and mixing it with a binding material. Presently, maize starch is used as a binding material, in a ratio of 30 kg starch per tonne of charcoal.

Briquetting takes the braided charcoal and mechanically presses it into uniform densified *briquettes*.

Drying. The briquettes are transferred to driers which use coffee husks as a fuel. Once their moisture content is reduced to an acceptably low level the briquettes are ready for packaging and transport to market.

KPCU's charcoal output was about 150-200 tonnes of charcoal per month as of 1987 and their projected output is 300 tonnes per month. The charcoal, called Kahawa Coal, is sold locally in Nairobi and also exported to Europe and the Middle East. As the price of wood charcoal rises, Kahawa Coal is becoming more and more economical.

Although coffee charcoal has lower energy content by weight than wood charcoal (because of its higher ash content), the densification of the briquettes gives them a higher energy content per *volume* than wood charcoal.

Organisation of the Charcoal Industry

Organising the charcoal industry could help increase charcoal conversion efficiency, decrease the price of charcoal and protect fragile environments now being damaged by charcoal makers. Several stratagies which have been recommended are listed below.

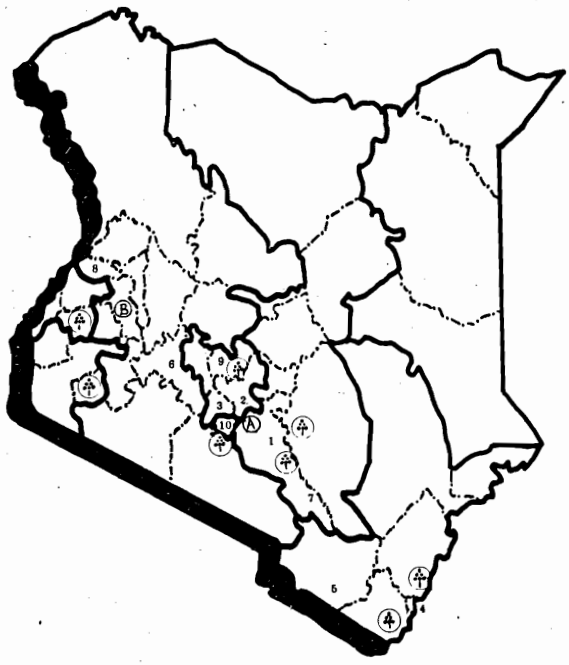
- Charcoal production centres which use efficient kilns (e.g. half-orange) could be set up in several areas.

- Charcoal-makers could be trained to improve their kilning methods. They could also be given tree planting responsibilities.

- Charcoal production co-operatives could be set up which would make capital available to charcoal-makers (for purchase of improved kilns). These organisations could also improve the marketing of charcoal products and limit the amount of tree poaching.

- The charcoal marketing and distribution system could be improved. This could lead to a higher producer price and a lower consumer price.

Agroforestry, Improved Stoves and Kilns



Improved Kilns

A Muka Mukuu (~10 half orange)

B East African Tanning Extract Co. (Beehive kilns)

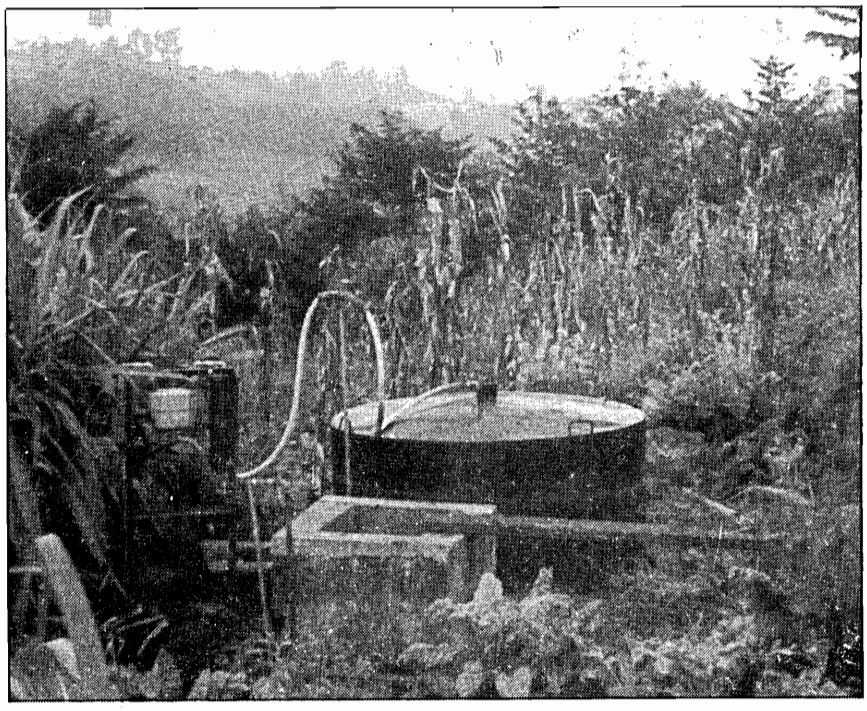
Agroforestry Centres

Agroforestry Centres (see Appendix)

- Agroforestry methods
- Wood and charcoal stoves
- Biogas digesters
- Half orange kilns

Bellerive Community Stove Examples

1. Machakos Teachers Training College
2. Thika High School
3. Alliance Girls School, Kikuyu
4. Mombasa Secondary School for the Physically Handicapped
5. Bura Girls High School, Taita Taveta
6. Kabarak High School, Nakuru
7. St. Joseph's Girls School, Kibwezi
8. Ortum Mission Hospital, Kitale
9. South Tetu Girls Secondary School, Nyeri
10. Dagoretti Childrens' Centre, Nairobi



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Non-Wood Biomass 4

Non-Wood Biomass Resources

Biomass is Kenya's most important energy resource. Biomass fuels include materials of organic origin such as wood, charcoal, maize cobs, coffee husks and animal wastes. Wood and charcoal, which together supply about 75% of Kenya's energy needs, have been discussed in the previous chapter. This chapter discusses fuel uses of *non-wood* biomass in Kenya.

Useful non-wood biomass include agricultural and animal wastes, together with crops which may be grown for the energy they contain (i.e. sugar). The tables below show the many biomass by-products produced by agriculture and industry in Kenya.

Table 4.1 Major Non-Wood Biomass Products and Amount Used Industrially

BIOMASS	ANNUAL PRODUCTION (TONNES)	USED INDUSTRIALLY (TONNES)
Maize cobs + stalks	1,176,000	-
Bagasse	1,000,000-1,300,000	1,064,000
Sawdust	63,000	50
Coffee husks	35,000	7,800
Coconut shells + coir	20,000	-
Cashew nut hulls	9,000	1,300
Rice husks	8,000	-
Sisal wastes	4,800	-
Municipal wastes	100,000	-

Source: Kenya: Energy Efficiency in the Tea Industry, World Bank Dec. 1986.

Non-wood biomass by-products are used locally for four main purposes:

1. *Animal feed*
2. *Fertilizer/soil conditioner*
3. *Construction*
4. *Fuel*

Maize stalks and other plant residues are used as livestock feed during the dry season. Brewery wastes, coffee processing wastes and even sawdust are added to cattle and pig feed to increase its food value.

Wastes from cattle, goats, sheep, pigs and chicken are used locally as fertiliser. Coffee pulp is re-applied to the soil as a fertiliser. Crop stalks are left standing and then ploughed back into the fields to act as soil conditioners.

Cattle dung is an important construction material. Significant amounts of cow dung are collected and mixed with clay and ash to build walls and floors of houses all over Kenya.

Table 4.2: Estimated Annual Animal Wastes by Province, Kenya 1980 (1)

MILLIONS OF TONNES AIR DRY WEIGHT

Province	Cattle	Sheep Goats	Pigs	Poultry	Donkeys	Camel
Nyanza	0.66	0.06	0.00	0.07	0.01	-
Western	0.44	0.02	0.00	0.05	0.00	-
Central	0.33	0.07	0.01	0.02	0.00	-
Nairobi	0.01	0.00	0.00	0.00	0.00	-
Eastern	1.10	0.22	0.00	0.06	0.02	0.29
Coast	0.22	0.05	0.00	0.02	0.00	-
Rift Valley	2.31	0.37	0.01	0.02	0.07	0.29
North Eastern	0.22	0.02	0.00	0.00	0.00	0.14
Total	**5.29**	**0.81**	**0.02**	**0.24**	**0.10**	**0.72**

(1) It is assumed that only 2% of the total animal waste is practically available. This percentage may increase as other energy sources become scarcer.

Source: Beijer Institute, 1980

Although this chapter discusses energy or fuel uses of biomass, the *fodder*, *construction* and *fertiliser* uses should also be regarded as important. In fact, the above uses of agricutlural wastes are often more important than fuel uses, and only those people who live in areas of wood or fuel shortages are forced to cook with agricultural wastes. Burning cow dung, for example, is a much less valuable use of that biomass than applying it to cropland or using it to build houses.

Non-Wood Biomass as Fuel

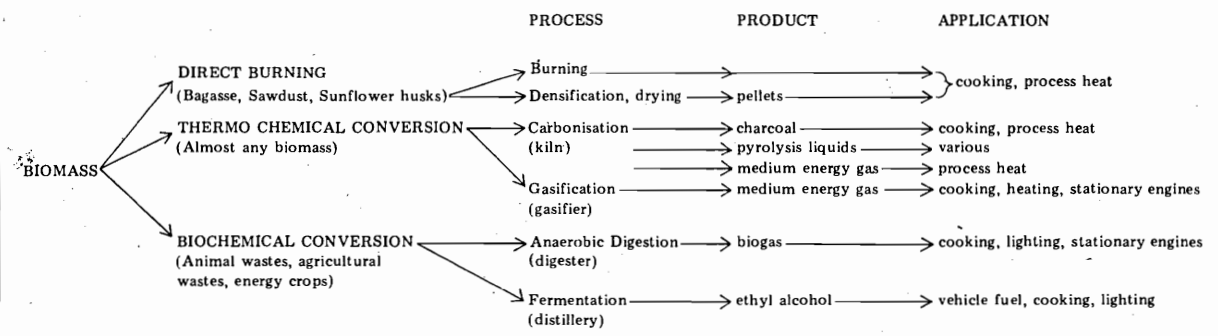
In places where biomass is collected centrally (i.e. bagasse at sugarmills, coffee husks at processing plants, etc.) or where there is a fuelwood shortage, non-wood biomass may be used economically as a fuel. There are three ways in which biomass can be used or converted into fuels.

Direct burning: Biomass material is combusted directly for the heat it contains.

Thermo-chemical conversion: Biomass material is wholly or partially carbonised to derive useful gaseous, liquid or solid fuels such as producer gas, methyl alcohol or charcoal.

Bio-chemical conversion: Biomass material is anaerobically treated or fermented by a biological agent (yeast, bacteria) to produce fuels such as ethyl alcohol or biogas.

Biomass as Fuel



Burning Biomass Directly

Provided there is a continual source of clean dry biomass, its direct burning can produce heat for cooking, heating water, industrial processes and electrical generation.

People in areas suffering from wood shortages are increasingly forced to use agricultural wastes and cow dung as a cooking fuel. In India, cow dung is dried and sold in markets specifically for cooking. The practice of burning cow dung as a fuel, however, is environmentally dangerous. Dung is a valuable fertiliser in farming areas and burning it releases its nutrients into the atmosphere. Furthermore, the smoke it gives off while burning is unhealthy for the lungs and the eyes. Despite the environmental and health dangers, more and more people in such areas as Nyanza and Western Province are burning cow dung and agricultural wastes as fuel.

In certain places, large amounts of agricultural wastes are centrally collected. These wastes include bagasse (Western Kenya) , coffee husks (in Dandora), rice husks (in Mwea), coconut shells and coir (at the coast), maize cobs and stalks (in Uasin Gishu, Trans Nzoia and Bungoma) and sawdust (at sawmills all over the country). These agricultural wastes are difficult to dispose of, and using them as cooking or heating fuels should be encouraged to help solve both the disposal and local energy problems. *Consider the following examples of wastes used as fuels:*

Bagasse

More than 1,000,000 tonnes of *bagasse* (de-juiced sugar cane stalks) provide fuel for processing both sugar and fuel alcohol. Sugar mills such as the one at Mumias burn bagasse in their boilers to generate steam for turning electrical turbines, which in turn supply the mill with electricity (bagasse accounts for 25% of all electrical generation in Mauritius). Bagasse also provides direct heat for sugar processing. One hundred thousand tonnes of bagasse are available to be burned as fuel in Nyanza and Western Provinces.

Sawdust

Wherever there are sawmills, *sawdust* is freely available. It is estimated that more than 63,000 tonnes of sawdust are produced annually in rural sawmills all over Kenya. Very little of it is used. The sawdust stove (described below) or the Wonderstove (described in this chapter) make it possible to use sawdust as a fuel for cooking. Stoves like the one described below are made by artisans in Karatina and by the Prisons Department. In Wanyororo, Nakuru, they are said to be common household items.

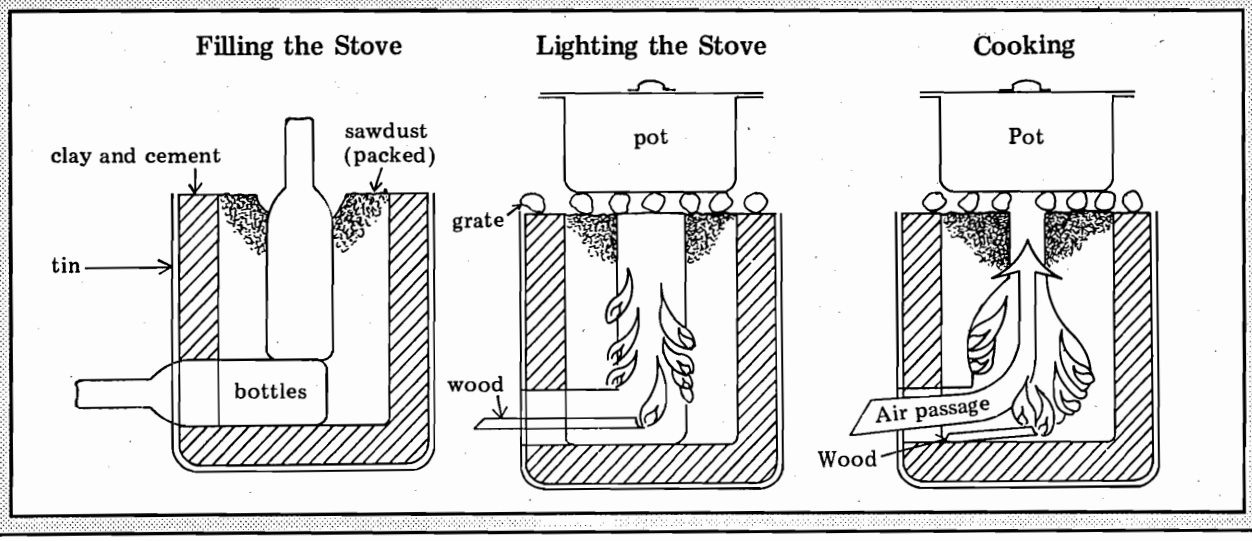
Example : The Sawdust Stove

Sawdust can be used as a fuel for cooking with this simple stove made from a tin can about the size of a metal *jiko*. A circular hole of 10 cm in diameter is cut near the bottom of the tin. Then the inside is plastered with a layer of clay and cement several centimetres thick. Iron or steel rods placed across the top of the tin act as a support for the cooking vessel.

When using the stove, two bottles are placed inside as shown and the space around them is packed with sawdust. The sawdust is packed tightly, and then the bottles are *removed*, leaving a space that acts as an air channel for the fire.

A piece of firewood about half the thickness of the bottles is dipped in paraffin, set alight, and pushed into the bottom part of the air channel. When the sawdust begins to burn, the pot is placed on the supports. The firewood is slowly pushed further into the opening as it burns.

Air enters the air channel at the bottom, is heated and passes upward over the surface of the sawdust. The sawdust burns outward, leaving an onion shaped cavity inside the stove. Several 30 cm lengths of wood (2 cm diameter) and a full chamber of sawdust are sufficient to provide a cooking flame for about two hours with this method. (Adapted from *Wood Conserving Cookstoves: A Design Guide* , VITA 1982).



Coffee Husks

A significant amount of the over 35,000 tonnes of coffee parchment husks produced annually at factory sites is dried and sold for direct burning. In Dandora, Kenya Planters Cooperative Union (KPCU) carbonises over 1,200 tonnes of charcoal per year. An even larger amount is sold for direct burning to East African Industries, Ltd. and clay-firing industries around Nairobi.

Rice Husks

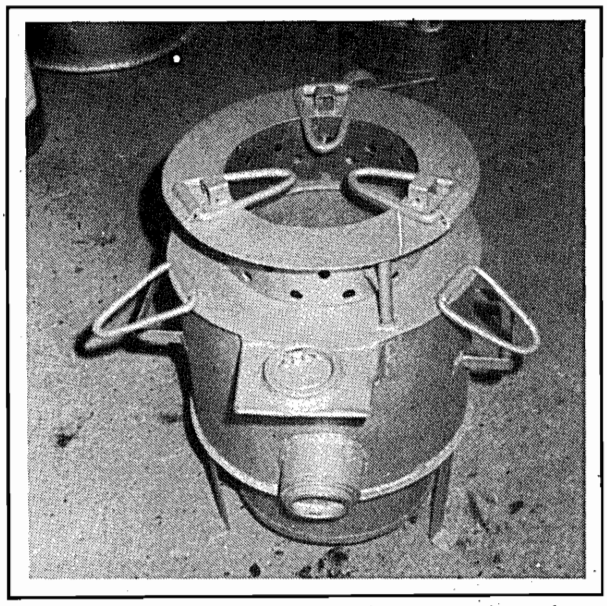
In Mwea and Nyanza, Kenya's main rice producing schemes, large piles of rice husks are deposited outside the hullery after harvesting. These piles are eventually burned because the rice industry cannot dispose of them. However, some people have found that with the Wonderstove they can cook all of their meals using rice husks as fuel. Many rice producing countries use rice husks as an industrial fuel, and Kenya's annual production of 8,000 tonnes can be a significant source of energy.

Other Potential Waste Biomass Fuels

Wherever large amounts of biomass wastes are produced there may be a potential for burning them directly as fuel. This is especially true when they are centrally collected in mills or processing plants.

Twenty five percent of each maize harvest (by weight) in Uasin Gishu, Trans Nzoia and Bungoma is maize cobs. Maize cobs are already burned as cooking fuels in many households. Coconut shells and coir that accumulate in waste piles in such urban areas as Mombasa and Malindi can be used as industrial or cooking fuels.

Sisal wastes, municipal paper wastes, cashewnut shell wastes and even pineapple wastes can all be dried and burned for their energy value. One sunflower seed oil extracting company, as a final example, burns sunflower husks in their boiler to produce the heat energy that allows them to process sunflower oil.



The Wonderstove uses such powdered wastes as rice and coffee husks or sawdust as cooking fuels.

Densification

Densification is a process by which biomass is first *dried* to a certain moisture content and then mechanically compressed to form *briquettes*. Because the briquettes have a specific size and moisture content, they contain a constant energy value and are thus useful for industrial or domestic heating purposes. As an example, pineapple wastes have been densified in the Phillipines to produce briquettes for industrial heating. Densification of sawdust or rice husks may be feasible in Kenya.

East African Packaging Company (EAPC) presently densifies coffee parchment husks (from KPCU) and wood chips (from Timsales) to make briquettes. The briquettes are used by EAPC to raise process heat for the manufacture of cartons.

Thermo-chemical Conversion of Biomass Wastes

All biomass breaks down into more simple molecules at high temperatures. By controlling the temperature, pressure and oxygen supply, and by using various catalysts, more useful fuels can be derived from waste biomass. There are two general methods of thermo-chemically converting biomass to more useful fuels in Kenya:

1. *Carbonisation* : the heating of biomass material to a high temperature in the absence of air.

2. *Gasification* : the controlled combustion of part of the biomass in order to convert the rest to a low to medium heat value gas.

Carbonisation

Carbonisation of wood and coffee husks in Kenya is discussed in the preceding chapter. Carbonisation of agricultural wastes makes a charcoal product which is transportable and marketable. One study done in Canada during the 1920s demonstrated that a tonne of sun-dried wheat straw, when heated anaerobically to 500-600°C, could yield about 300 kg of charcoal, 38 l of wood oil and 280 m^3 of medium energy gas (15,000 kj/m^3). If there is equipment to recover the gas and liquid products, carbonisation can yield over 80% of the original biomass material's energy.

A carbonisation process called destructive distillation can produce methyl alcohol from biomass. However, carbonisation processes used in Kenya do not collect liquid or gas products as charcoal is considered the most important product. Currently, coffee husks and macademia nut shells are locally converted into charcoal, and carbonisation of coconut shells has been experimented with.

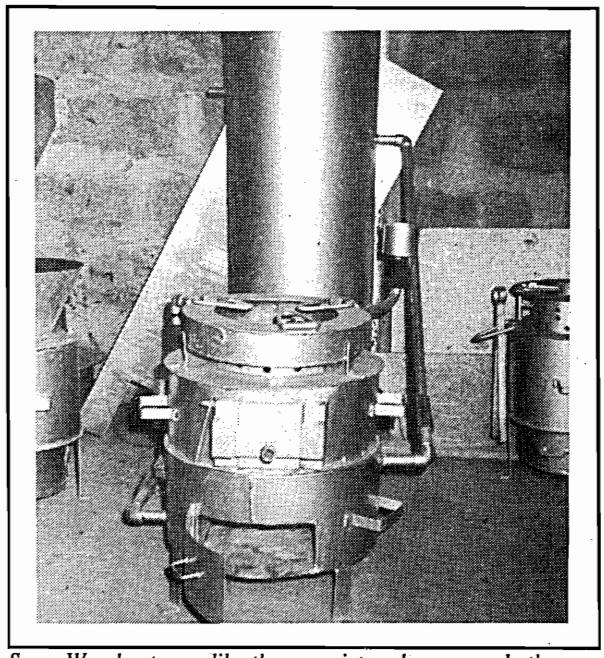
Gasification

The gasification process breaks biomass wastes down completely, enabling the energy in solid wastes to be used in a more convenient gas form. The efficiency of the process can be as high as 85%. A major drawback of gasification is that it requires constant maintenance, especially when the gas produced is used to run engines.

Gasifiers, also called gas generators, have been operated with such fuels as wood chips, charcoal, coconut husks, dung and maize residues. The gas given off, called *producer gas* (5,000-7,500 kJ/m^3), typically runs stationary or vehicle engines (after being filtered and cleaned) or is burned directly to supply industrial and cooking heat. Gasifiers were widely used to power vehicles during World War II when there was a shortage of petroleum in Europe.

One company in Nairobi has produced gasifier systems that use woodfuel (as well as other dry biomass) to power engines and large-scale industrial processes (kilning and drying). However, gasifiers have not met with a lot of success for powering engines in Kenya because the pipes in the engines tend to get clogged with tars if the systems are not well maintained (See appendix, AMICA Gasifiers).

Wonderstove gasifiers , however, which use this gas for cooking, are being successfully marketed in Kenya. The stove produces gas from any fine, dry biomass burning the gas as it is produced for cooking.



Some Wonderstoves, like the one pictured, serve as both stoves and water heaters.

Example: Wonder Gas Stoves

At least one local Nairobi company, Apro Energy Enterprises Ltd., has begun to market devices that make use of the energy in waste biomass by *partial gasification*. This company presently designs, builds and markets cookstoves and water heaters (non-electrical geysers) that use dry biomass wastes as fuel. The first Wonder Gas stove was put in the market during June 1984 and since that time hundreds of stoves have been sold.

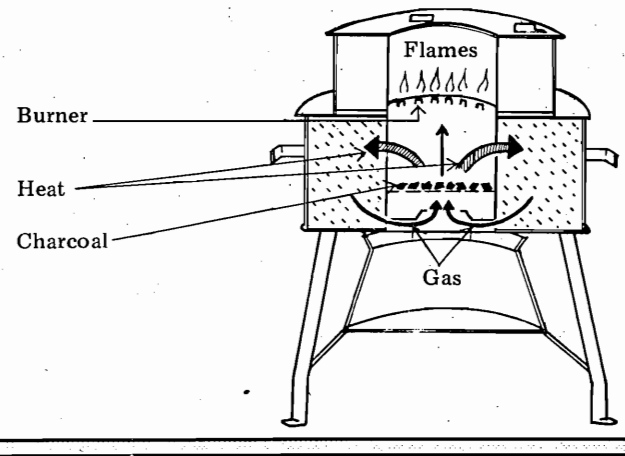
Wonder Gas stoves operate using any powdered form of biomass. Rice husks, sawdust or coffee husks are placed in the chamber surrounding the grate, and then a small amount of charcoal is lit on top of the grate. Heat from the burning charcoal is conveyed into the biomass chamber, raising the temperature of the material inside.

Because there is no oxygen in the chamber, the biomass does not burn and instead undergoes pyrolysis, giving off volatile gases which include oxygenated hydrocarbons and hydrogenated carbons. The gases produced by this *partial gasification* exit through an opening beneath the grate and undergo thermal cracking after which carbon particles in the gas are deposited on the burning charcoal. Finally the gases move out through the burner and are combusted beneath the pot as with a gas cooker. The remaining solid biomass in the chamber is carbonised forming a charcoal powder which can be mixed with a suitable binding material (ie. clay) and used to make briquettes.

Through continuous efforts to improve them since 1984, the stoves have been made safer, more efficient and easier to operate. They save 80% of the charcoal fuel that had been used to cook before. For example, with the Wonderstove 2.5 kilogrammes of charcoal are used to cook for four hours, making food for fifteen people and heating 120 litres of water to 60°C. The stoves can be adapted to use charcoal only for fast cooking jobs such as boiling tea. Furthermore, some of the stove designs have a built-in water heating system that efficiently utilizes escaping radiation to warm water. There are several models of Wonder Gas stoves available, ranging from the cheap *wananchi* model to a community stove which can be used at institutions which have plentiful sources of waste biomass.

Hundreds of Wonder Gas stoves have been sold, especially in Kericho, Sagana, Nairobi, Kisumu and Mombasa. In addition, some have been exported to Tanzania, Uganda and Zimbabwe. Institutional stoves that use sawdust to cook meals can be found at Laiser Hill Academy outside Nairobi and Migwani High School in Kitui. Apro Energy Enterprise has also sold water heaters powered by biomass to tourist lodges in Masaai Mara and Amboseli.

Cross Section of Wonder Stove



Bio-chemical Conversion of Biomass

Bio-chemical conversion makes use of biological processes which convert biomass energy into useful liquid or gaseous forms. Production of fuel alcohol and biogas from biomass materials has become increasingly important in countries without petroleum reserves.

Biogas is produced by the action of anaerobic bacteria on most non-wood biomass material in oxygen-free environments. Because of the potential which biogas digesters have in rural Kenya, they are discussed in detail in the next section.

Power Alcohol

In the past twenty years, production of ethyl alcohol *(ethanol)* from certain crops for fuel has received much attention. Ethanol, which is mixed with petrol to make gasohol (80% petrol, 20% ethanol), is one of the few renewable energy fuels that can easily be used to power vehicles.

During the oil crisis of the 1970s, countries such as Brazil and the United States developed ethanol producing programmes in order to protect themselves from rising petroleum prices. Later, other countries developed ethanol programmes (these include Zimbabwe, Malawi and Kenya in Africa) with the goal of easing their dependency on imported petroleum.

Fermentation of crops to produce ethyl alcohol is an ancient practice. People in Kenya have been fermenting sugar-rich substances such as honey, millet and sorghum for hundreds of years. In the past, however, the fermented and refined product has been used as a *drink* and not a fuel.

How alcohol is produced

fermentation *distillation*

Sugars ----------> Beer (ethanol 6-12%) ----------> Alcohol (80-95%)

(honey,millet,sorghum) (*uki, busaa,* Tusker) (*chang'aa,* Kenya Cane etc.)

Brazil's Ethanol Programme

Brazil has been actively promoting ethanol production for over 25 years in order to reduce the country's petroleum expenditures. Much land has been put into sugar-cane production, while some of the sugar cane originally used in sugar production is now used to make ethanol. Brazil is now making ethanol from cassava to diversify its alcohol production.

The industry produces almost 4 million tonnes of alcohol annually. All petrol sold in the country is gasohol containing 20% ethanol. Furthermore, more than 200,000 vehicles built by Brazil's motorcar industry run on 100% alcohol.

Industrial Production of Power Alcohol in Kenya

A large plant in Muhoroni, near Kisumu, presently produces all of Kenya's power alcohol. Ethyl alcohol production at the plant uses molasses, a by-product of the sugar industry, and some sugar-cane as raw materials. Industrial production of ethanol involves 4 principle steps:

1. Preparation of molasses or crushing of sugar-cane to obtain juice.
2. Fermentation of juice with yeast to yield 6-12% ethanol "beer".
3. Distillation of "beer" to obtain 95-96% hydrated alcohol.
4. Dehydration of alcohol to 99.5% pure alcohol.

When producing at full capacity, Muhoroni's ethanol output is over 45 tonnes per day. This *power alcohol* is transported to Nairobi where it is mixed with petrol to make gasohol.

Advantages and Disadvantages of Gasohol Production

Globally, gasohol is a frequently debated issue. Gasohol production creates jobs, and many people are employed in the power alcohol industry. The fact that Kenya produces its own fuel alcohol makes the country's transport industry more secure. When in the long term petroleum prices rise again, locally-produced power alcohol will become more valuable to the economy. Another argument in favour of gasohol is

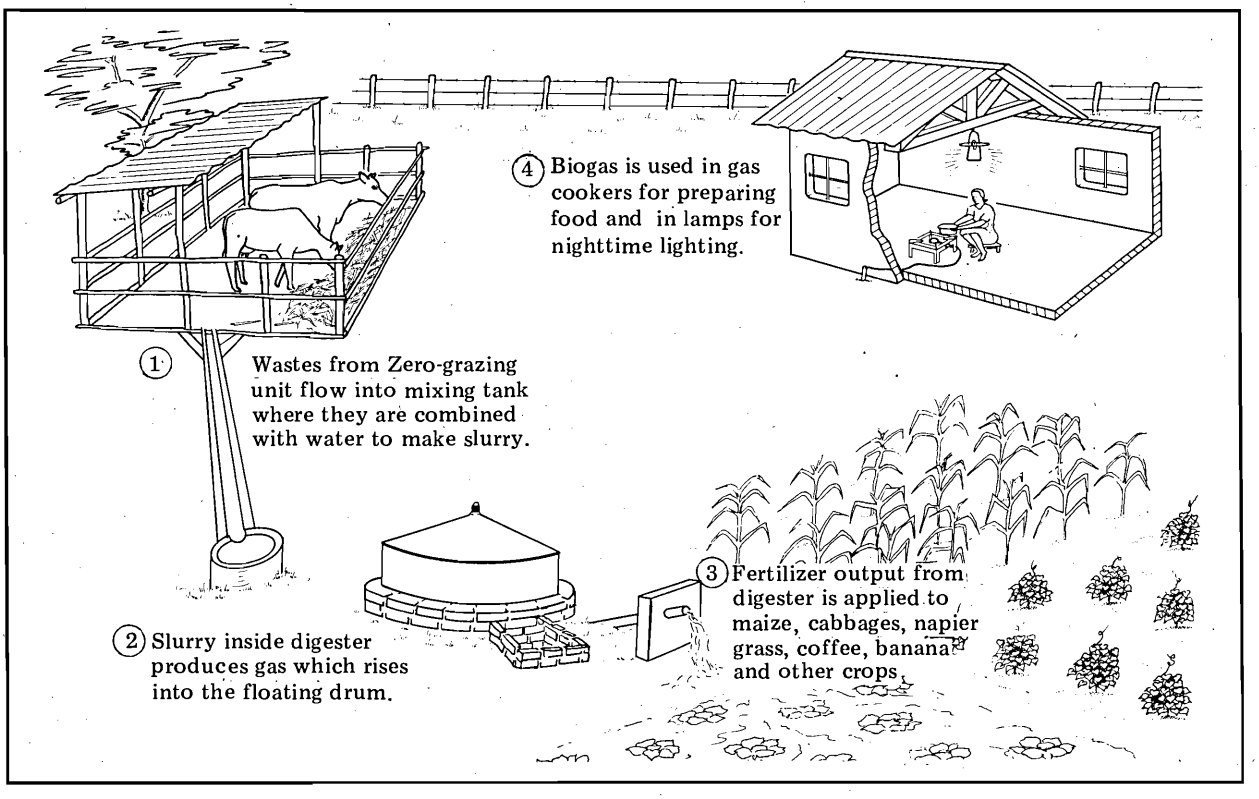
Gasohol is sold in petrol stations throughout Nairobi.

that stillage, the by-product of fermentation, can be returned to land under sugar-cane production as fertiliser.

However, ethanol is presently much more expensive to produce than petroleum. It can not be mixed with diesel fuel, which is in short supply. Kenya's sugar industry is not as large as Brazil's, and the raw materials (i.e. molasses, sugar-cane) for making alcohol are limited. In fact, there is not enough molasses presently available locally to increase Kenya's alcohol production.

The country's agricultural land is limited. Most of this land is necessary for achieving food self-sufficiency. If more high potential land is used to grow sugar-cane for alcohol, less land will be available for growing food. This problem could be solved by using cassava and sweet sorghum as feedstocks for alcohol production (these can be grown on marginal land), but this solution requires much research.

Finally, disposal of stillage has turned out to be a problem because it must be treated before being transported to sugar-cane fields. Treating and transporting stillage requires more money and equipment.



Biogas Digesters

Biogas

Biogas is a combustible gas produced by the fermentation of organic material in the absence of oxygen. It is composed of about 60% methane (CH_4) and 40% carbon dioxide (CO_2). It has a faint smell that is not unpleasant. Biogas burns with a hot blue flame, and can be used for cooking with a gas burner. It is also used in gas lamps, to run refrigerators and to power stationary diesel and petrol engines.

Digesters

Digesters are sealed continers that enable biogas production to occur. Organic matter such as cow dung, pig wastes, vegetable wastes or even human faeces is mixed with water and poured into the biogas digester. Several species of *anaerobic bacteria* (bacteria that live only in conditions without oxygen) "feed" on this organic matter and give off biogas as a by-product of their life activities.

Biogas digesters are specially built to keep the conditions for the anaerobic bacteria constant and to capture the gas that they produce. Biogas has become popular in Kenya as a renewable energy source, but it has several other important applications.

Applications of Biogas Technology

Biogas fuel: The manure from four grade zero-grazing cattle will produce enough gas for the cooking and lighting needs of an average rural family. Biogas is economical for farmers with enough zero-grazing cows and resources to construct the digester. Use of biogas helps prevent deforestation because it decreases reliance on woodfuels.

Fertiliser production: The liquid by-product of the fermenting process, called *effluent*, is a better quality fertiliser than undigested wastes. It contains more

available nitrogen than manure (in the form of ammonia).

Sanitation: Potentially harmful wastes of cows and pigs are removed from zero-grazing enclosures. Flies cannot breed, and unpleasant odours are removed. Livestock are healthier, live longer and produce more milk.

History of Biogas Technology

Biogas technology has been in use since the late 1940s. The original purpose of biogas was not production of fuel gas, though. Initially, biogas digesters were used for the purpose of treating wastes and producing fertiliser. They have been important in development activities in China and India primarily because of their use as *sanitation* and *agricultural* tools.

Biogas in China

The Peoples Republic of China was a poor country after its 1949 revolution. Its people suffered from water-transmitted diseases such as cholera, typhoid and dysentary, and from such parasites as schistosomes and hookworms. There was very little foreign exchange to support the agriculturally based economy. Money for fertiliser and petroleum products was scarce. The population was growing quickly and deforestation was a major problem.

Fertiliser shortages and water-transmitted diseases were widespread in rural areas. Because of the fertiliser shortage, people used whatever wastes were available as fertiliser for their crops. Many people poured untreated human excreta directly into their rice and maize fields. Since rice (the staple food of China) is grown in water, many "paddies" became contaminated with water-borne diseases (typhoid, schistosomiasis). These diseases and parasites were transmitted via human wastes. Although the use of untreated wastes as fertilisers is dangerous, people were forced to use them because no other type of fertiliser was available.

For health and economic reasons, the Chinese government began to recommend anaerobic waste treatment plants to its population. The anaerobic conditions in biogas plants kill disease organisms and parasite eggs. China thus managed to successfully control cholera, typhoid and schistosomiasis (bilharzia) with the help of biogas plants.

These waste treatment plants not only made dangerous wastes safe to use as fertilisers, they also increased the potency of the fertilisers. Fertilisers from digesters often increased crop production by 15% over previous yields. Through the use of biogas digesters, China's agriculture became more productive. Remote areas produced their own fertiliser and their own cooking fuel.

As the biogas programme continued, digester designs were improved and made cheaper. Many people were trained to build biogas digesters and appliances, creating additional employment.

To date 8 million digesters have been built in China. These digesters produce thousands of tonnes of fertiliser per year. Thousands of biogas digesters have also been built in India, Nepal, Korea, Thailand, Europe and the USA.

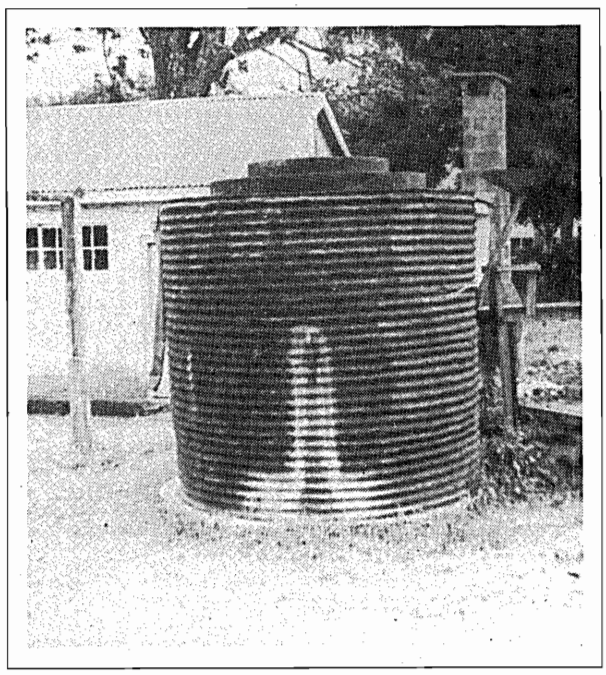
Biogas in Kenya

Although the technology has been available in Kenya since the 1950's, biogas digesters did not immediately become widespread. Most small farmers were unaware of the technology or were unable to make the relatively high initial investment on an "unproven" technology. Because of the rural energy crisis and the fertiliser shortage, the government is now promoting biogas as an energy source.

Mr. Tim Hutchinson, a European farmer, built the first biogas digesters in Kenya. Having heard about biogas digesters operating abroad, he began to experiment with digester designs on his coffee plantation. By 1957, he had built Kenya's first biogas digester, and it was providing all of the gas and fertiliser that his farm needed. He found that *effluent* (or "sludge"), the fermented waste material, was an excellent fertiliser, and that upon its application to his coffee trees they produced more coffee. In 1958, he started constructing biogas digesters commercially from Fort Ternan.

Between 1960 and 1986, Hutchnison's company (called Tunnel Engineering Ltd.) sold more than 130 small biogas units and 30 larger units all over the country. Hutchinson biogas digesters still working after twenty years can be found in many parts of Kenya.

Hutchinson proved that biogas digesters can work in Kenya. He also did important work with the Coffee Research Foundation showing that biogas effluent is a *better* fertiliser than commercial fertilisers.



Hutchinson biogas digester, Chogoria. This is an example of biogas project that has failed due to poor maintenance.The gas appliances in the house behind the digester have broken down and the occupant was last cooking with charcoal even though gas was still being produced.

Why Biogas Plants Fail

During the last twenty years, hundreds of biogas digesters have been built in Kenya by volunteers, missionaries and Kenyan nationals. Unfortunately, most of these digesters fail eventually, and biogas technology has acquired a bad reputation. There are three main reasons why biogas projects fail:

Poor maintenance. Volunteers build digesters and then leave the country without properly explaining how to care for them. In other cases people simply stop maintaining them. They stop adding manure or they do not repair the gas holder.

Poor planning. It is important to consider *why* one is building a biogas digester. Both gas and fertiliser are by-products of biogas digesters. If there is no use for the fertiliser produced, then much money and work will have been spent to collect a comparatively small amount of gas. Before building, one must be sure there is enough *organic material* and *water* to "feed" the digester. Biogas digesters often fail because of shortages of water or feedstock. Remember, biogas digesters are methane gas producing fertiliser plants as well as sanitation aids. Many bags of charcoal can be bought for the money it takes to build one biogas digester.

Poor construction or design. Many people have seen working biogas digesters and attempted to build their own. However, biogas digesters are not as simple as they look. They *must* be properly designed and constructed. If an unqualified person attempts to build a digester, he will probably run into problems. People have been trained to build biogas digesters in Kenya and interested farmers should enlist the help of these qualified biogas constructors.

Recent Developments

At least 250 biogas digesters were operating successfully in Kenya as of 1987. Hutchinson digesters work well in most places where they are maintained. The Ministry of Energy and Regional Development supports programmes which are demonstrating digesters and training biogas builders at the district level. These programmes are located where there is high agricultural activity, and where zero-grazing is common.

The Ministry promotes a locally-tested design called the *Sasse-Borda digester*. By 1987, almost 150 Sasse design digesters had been built in Meru, Murang'a, Nairobi, Kilifi, Kisii and Kakamega. The demand for these biogas plants is increasing rapidly.

Biogas Potential in Kenya

Biogas digesters are among the most promising renewable energy technologies for the future in rural Kenya. The methane gas produced is a safe, proven fuel for lighting, cooking or running generators. The fertiliser output improves the quality of farm soil and leads to higher crop yields.

Table 4.2 (see page 76) describes animal waste resources by province in Kenya. Considering that the wastes from two zero-grazed cows can produce more than one cubic metre of biogas per day, enough manure is produced by the cattle in Kenya to generate 5 million cubic metres of gas each day. Although collecting the manure from all of the cattle in Kenya each day would be an impossible task (and building the required digesters would be very expensive), the amount of gas that can be collected from all the cattle *"bomas"* and zero-grazing enclosures is very great. The tables show the very large amounts of waste material available from sheep, goats, pigs, camels, donkeys, poultry and agricultural in the country.

Biogas digesters are not cheap. The high cost of a biogas digester and zero-grazing unit discourages very many farmers. But the benefits to a farmer with three or four head of cattle are great. Money is saved on fertiliser and crop yields improve. The cattle live in healthier conditions. Money is saved on fuel for cooking and lighting. A farm's self-sufficiency and productivity is increased with a working biogas digester.

Types of Biogas Digesters

Batch Digesters

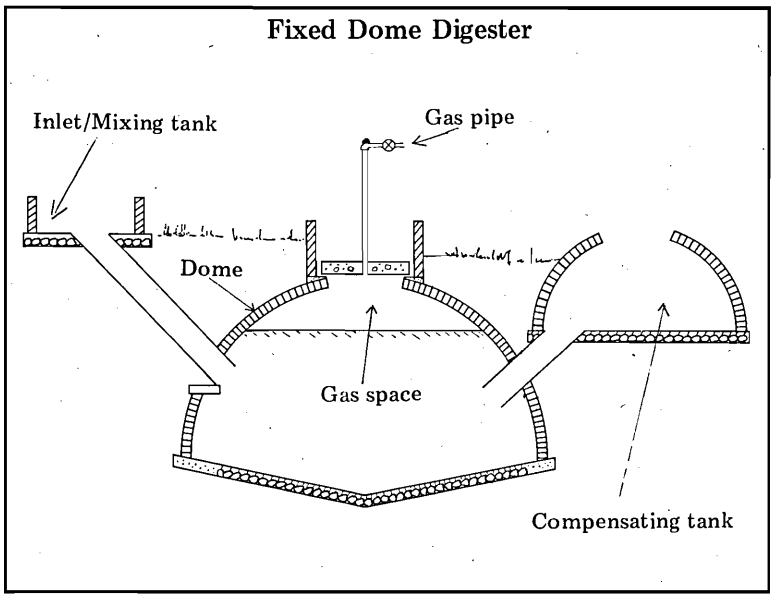
Batch-type biogas plants are used in large farms and commercial operations where organic material is available seasonally. One "batch" of feed material is added to the digester and left to ferment for a certain period of time. When the material stops producing gas, it is removed from the digester and a new load of feed material is added.

Batch digesters are useful when feed materials are produced in large amounts on a seasonal basis. For example, large coffee farms in Kenya have used batch digesters to ferment the large amounts of coffee pulp available twice a year. Batch digesters are also useful when the fertilising effluent is needed in large amounts during certain times of year. The main disadvantage of these digesters is that gas is not continuously available unless there is either a very large gas holder or many digesters.

Continuous Flow Digester

Much more common than batch digesters, these biogas plants require that feed materials be added regularly. They are useful on small farms where organic material is available on a daily basis. Continous flow digesters, which produce gas at a constant rate, can be divided into three groups:

Floating drum. (See Sasse description page 87). The Sasse and Hutchinson designs are examples of floating drum digesters. A large inverted drum that stores gas is the identifying feature of this digester type first developed in India. Floating drum digesters are easy to operate and construct but the large steel drum makes them relatively expensive.



Fixed dome. These Chinese-type digesters have an underground, non-moving gas space called the dome. Gas accumulates in this dome and forces slurry to be displaced into a compensating tank. Operation of fixed dome digesters is different from floating drum digesters because effluent does not flow out of fixed dome digesters by gravity. Instead, each time a volume of fresh slurry is poured into the inlet, an equal volume of effluent must be removed from the compensating tank.

Because of their few steel parts, fixed dome digesters have low construction costs and long lifetimes. However, gas pressure is not constant and the gas volume cannot be seen (as it is underground). As well, gas leaks may develop in small cracks in the dome and operation of fixed dome digesters is not as simple as that of floating drum digesters. Fixed dome digesters should only be built by experienced, qualified biogas masons.

Balloon digesters use a tough plastic, canvas or rubber balloon (bag) to hold the slurry and collect the biogas. The balloon, much cheaper than a steel drum, is installed in a freshly dug hole, avoiding masonry work. The inlet and outlet are attached directly to the balloon and manure is poured in with water. Gas collects in top part of the bag and is piped to the place where it is needed.

Balloon biogas digester are cheap, easy to transport, build, maintain and operate. In sunny places, they operate at high temperatures. However, they are not permanent and they may be punctured easily. Presently they are being used experimentally in Ethiopia.

The Digestion Process

Biochemical Principles

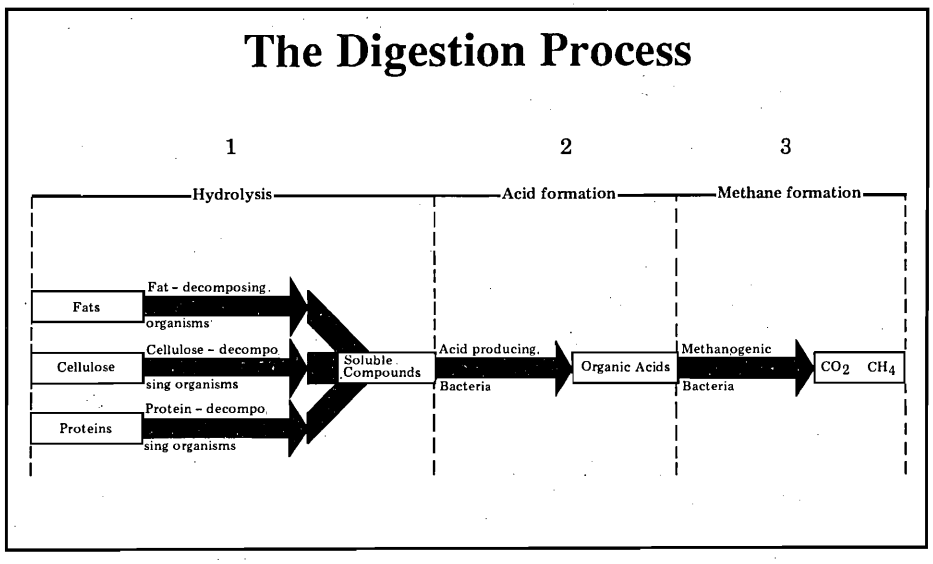
Biogas is formed when certain types of bacteria break down organic material in the absence of oxygen. These bacteria are called *anaerobic bacteria* because they live in places where there is no oxygen.

Many types of organic matter (called *feed material*) are used in digesters. Any animal or plant wastes (excluding wood) can be used as feed material if it is properly prepared. The most common materials used to "feed" digesters in Kenya are cow dung and pig wastes.

Feed materials are mixed thoroughly with water at a ratio of about one part feed material to one part water (depending on the feed material) in a mixing tank connected by a wide pipe to the digester. The feed material mixture, called *slurry*, passes into the digester and is acted on by the anaerobic bacteria.

There are many types of bacteria and several steps involved in the digestion process. The diagram below simplifies biogas production into three main parts, but the fermentation process is actually much more complicated, and the steps are inter-related.

Hydrolysis. In the first step, complex organic compounds, such as proteins, fats and cellulose chains, are converted to soluble simpler substances such as glucose and amino acids. The reaction, called *hydrolysis*, is the limiting (slowest) step in the fermentation process.



Acid Formation. During this second step, the simple compounds formed during hydrolysis are *fermented* to form carbon dioxide, various organic acids (formic, acetic, lactic, etc.), hydrogen and simple alcohols. This stage releases most of the energy which the anaerobic bacteria use for their life processes.

Methane Formation. During this stage, methane-producing bacteria (methanogenic bacteria) reduce carbon dioxide with hydrogen to produce methane and water:

$$CO_2 + 4H_2 \text{ ----------> } CH_4 + 2H_2O$$

Methane gas bubbles form during this stage and rise out of the mixture. Carbon dioxide not used in the reaction is also contained in these bubbles.

Conditions Which Effect Gas Production

Fermentation is caused by the action of many types of bacteria which live in the digester. If the conditions for the bacteria are not good, gas production will slow down or completely stop. Therefore, the owner of a biogas plant must make sure that certain conditions are maintained.

The biogas plant must be airtight and watertight. Anaerobic bacteria require oxygen-less conditions in order to live. Therefore, the digester should be open to air in as few places as possible. If the gas holder has a leak, biogas will escape. If the digester has a leak, slurry will seep out and production will slow down. Proper construction of the gas holder and digester is essential.

The temperature should be kept constant. *High temperature* fermentation (40°-55^oC) produces the most gas, but requires that the digester be heated. *Medium temperature* fermentation takes place between 30° and 40^oC. *Ordinary temperature* fermentation takes place from 10° to 30^oC and produces gas at a slower rate.

Digesters in Kenya operate at medium or ordinary temperature fermentation. The gas collector is painted black or red to absorb solar radiation during the day and thus raise the digester temperature. Rapid rises or falls in digester temperature will kill the bacteria. Therefore, digesters should be kept at a constant temperature.

The pH should be kept constant. Digesters that are functioning properly have a pH of around 7 which is neither acid nor base (i.e. neutral). If the slurry becomes too acidic (pH below 6.5) or too alkaline (pH above 8.5), the methanogic bacteria will be killed. When digesters become too acidic, lime is added until the pH of the slurry returns to around 7 again.

The digester should be given proper feed materials regularly. The bacteria require plentiful nutrients from feed materials which should contain carbon, nitrogen and inorganic salts in suitable ratios. The ratio of carbon to nitrogen should be about 20-25 carbon to 1 nitrogen. Cow dung, which is a good feed material, typically has a 25:1 carbon/nitrogen ratio. Regular feeding of the digester is essential for consistent gas production.

Water should be about 90% of the mixture. Water enables the feed material to flow easily in and out of the digester. When fresh cattle manure is mixed with water at a one to one ratio, the water content of the slurry is 92%. If there is too much water, the slurry will be diluted and the digestion process will slow down. If the proportion of water is too low, the slurry becomes acidic while a thick scum forms above it.

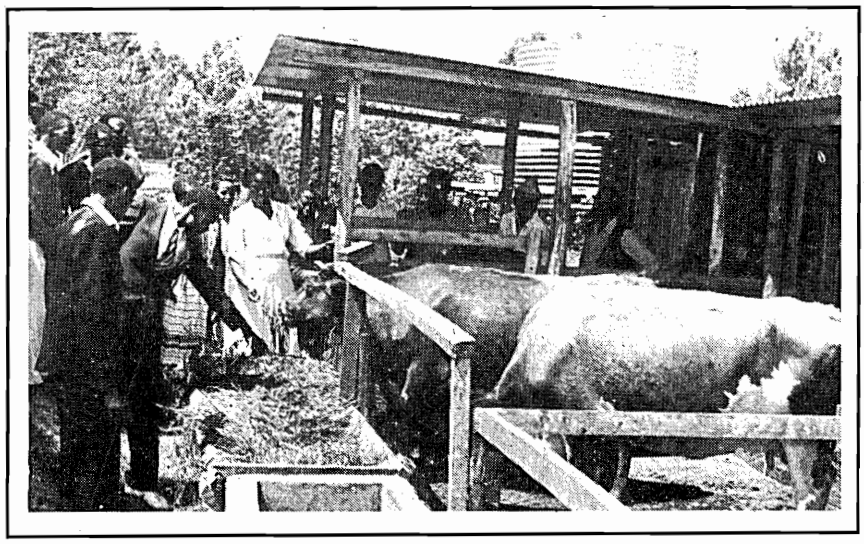
The digester contents should be stirred. If the slurry in the digester is not mixed, the materials inside will form layers. A sludge will form at the bottom, an *active* layer (where the gas is produced) will form in the middle, and a *scum* layer, which consists of light undigested materials, will form on top. Scum can completely stop gas production if it is not broken up by stirring.

Harmful materials must be kept out. High concentrations of toxic substances kill the biogas-producing bacteria. *Toxins* accidentally added to the digester such as copper ions, detergent compounds, sulphates or salt should be diluted by adding water to the digester and "flushing" them out.

Agricultural Uses of Biogas Technology

Biogas, Zero-Grazing and Animal Health

Zero-grazing has been adopted by many farmers in the highly populated areas of Kenya. Since there is no longer enough land on which to graze cattle, farmers have been forced to keep their cattle in enclosures



Zero-grazing enclosures should ideally be connected to biogas digesters

(*bomas*) and to feed them fodder grown on the farm itself (e.g., Napier grass, agricultural wastes). *Bomas* often have mud floors without roofs.

Standard zero-grazing units, improvements on traditional *bomas*, are built with concrete floors, feeding troughs, wooden fencing and *mabati* roofs. They protect cattle from rain and sunlight and are easily cleaned so that animals do not have to live in contact with their own wastes. There is less smell, and fewer flies and parasites. Cows kept in zero-grazing units produce more milk, live longer and are healthier than cows kept in simple *bomas* .

Biogas systems work best when integrated with zero-grazing units. Zero-grazing units are connected directly to the digester mixing tank so that all of the animal waste is washed through a channel into the tank. This saves work as manure does not have to be collected off the ground. Dirt, sand and pebbles do not accumulate in the digester. Furthermore, urine from the cows is also fed into the digester, adding more value to the fertiliser output. Farmers who have few cows (3-4) should build zero-grazing units before constructing digesters.

Biogas Effluent as a Fertiliser

Processed biogas effluent, a fertiliser of more value than cow dung alone, is the most important product of any biogas digester. Because biogas effluent (or sludge) improves soil *structure* over time, it is also more effective than commercial fertilisers.

The value of dung as a fertiliser increases as it is digested. Nitrogen previously unavailable to crops is transformed into ammonia (NH_3), which is water soluble and readily available to plants as a nutrient. Experiments in China have shown that the ammonia content of organic material fermented for 30 days increases by 19%. Phosphate content also increases significantly (see table 4.4).

A typical NPK ratio for biogas effluent is 2:1:2. This varies according to feed material and the effluent from feed materials with low carbon/nitrogen ratios make better fertilisers. Overfertilising is possible with biogas effluent; so farmers must find out the appropriate amount by testing. Crop yields of 15% over fields fertilised with fresh untreated manure are common. Best results are obtained when the effluent is mixed with composted material before being applied to crops (see table 4.5).

The fertilising effect depends on the type of crop and the type of soil. Effluent improves soil structure as, over the years, more and more humus is added to the soil, improving its water holding capacity. Nitrogen contained in effluent is released into the soil very slowly, so the soil remains potent even after several seasons.

A Sasse-design 9.4m^3 digester produces 50,000 litres of liquid fertiliser per annum from the wastes of five cows. This liquid fertiliser contains no pathogens, no weed seeds, no smell and does not attract flies. It is also used as a feed material for fish ponds.

Kenya's agriculturally based economy imports most of its fertiliser at a very high cost. This cost is paid by farmers. Biogas digesters are fertiliser producing plants that can be made with local materials. The agricultural benefits of the fertiliser, combined with the wood-saving benefits of biogas, give digesters a great potential for improving the national economy.

Table 4.4: Comparing Fresh Manure, Biogas Effluent and Commercial Fertiliser

FERTILISER TYPE	PHOSPHATE CONTENT (Parts Per Million)	POTASH CONTENT (PPM)	CALCIUM CONTENT (PPM)
Commercial NPK	15	3.45	5.1
Fresh cow manure	17	2.18	3.8
Digested effluent (sludge)	78	5.65	10.8

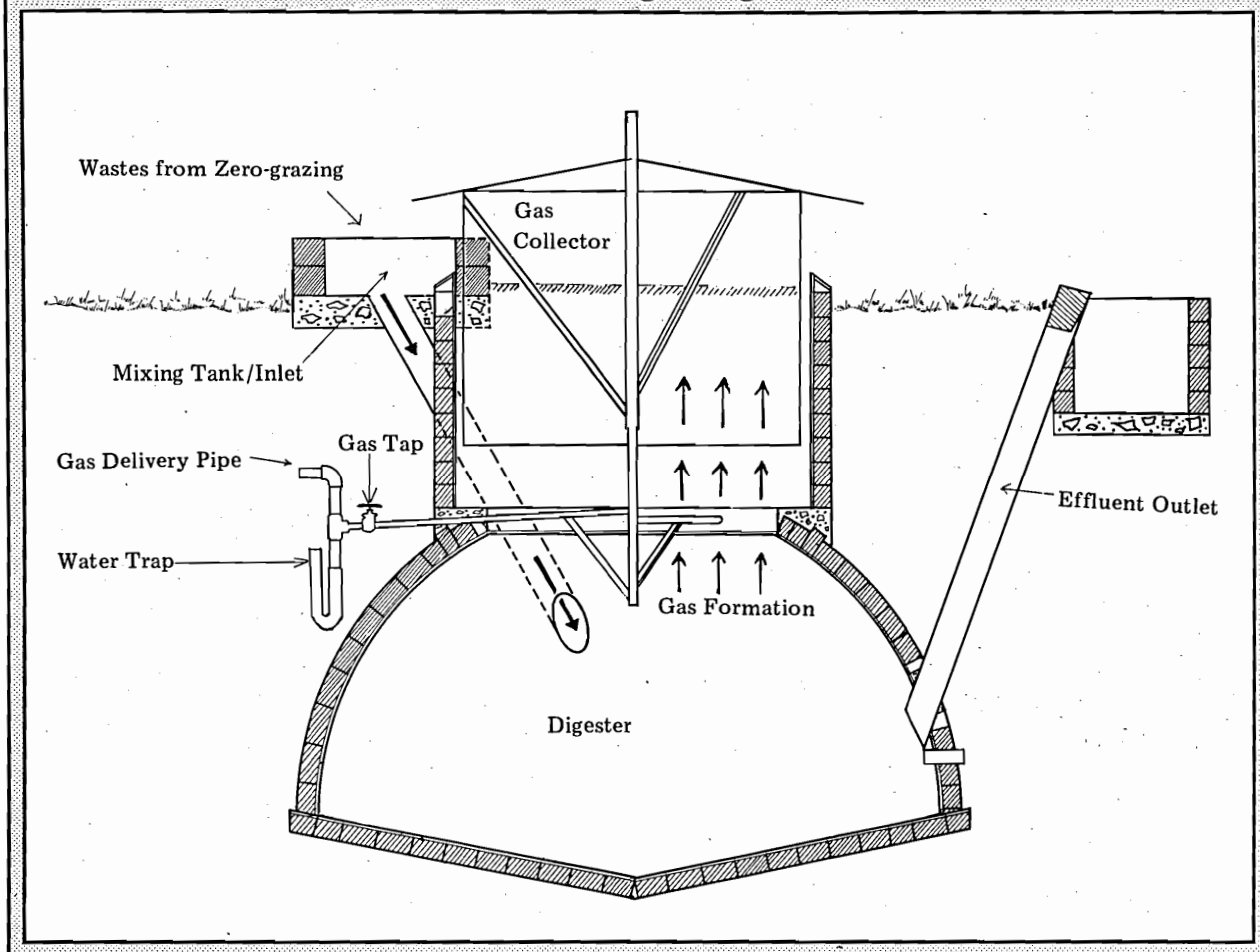
Source: Coffee Research Foundation/Tunnel Engineering, Ltd, 1969.

Table 4.5: Effect of Applied Effluent on Various Crop Yields (China)

CROP	AMOUNT OF EFFLUENT APPLIED (Kgs/ha)	YIELD (Kgs/ha)		YIELD INCREASE	
		Effluent	Control	Kgs/ha	%
Sweet potato	17,055	24,529	21,702	2827	13
Rice	15,160	6,609	6,056	553	9
Maize	22,740	5,060	4,682	378	8
Cotton	22,740	1,263	1,170	93	8

Source: Compost, Fertiliser and Biogas Production from Human and Farm Wastes in the Peoples Republic of China. Ed. M. McGary, J.Stainforth, IDRC, 1978.

Example : The Sasse/Borda 9.4 M^3 Biogas Digester



The Sasse/Borda model biogas digester has been tested extensively in Kenya and Tanzania. Its design has met success in East African conditions. The Ministry of Energy and Regional Development supports programmes which are building these biogas digesters in many parts of Kenya.

This digester operates most effectively with the manure from four or five cows (75 kg/day) and an equivalent mass of water. Well maintained digesters in warm areas produce over $3m^3$ of gas per day, enough to meet all the cooking fuel and lighting needs of a family of 4-7 persons.

Sasse digesters are recommended for farmers who already have zero-grazing units. Locally available materials can be used to build the underground digester (i.e. quarrystone). Skilled masons and welders should be employed to build the digester and gas holder.

Parts of the Sasse Digester

Mixing Tank and Inlet Pipe. Feed material is mixed with water in the cylindrically-shaped *mixing tank*. Sand, stones and other non-digestable materials are removed here. Slurry flows into the digester through the *inlet*. This inlet must be wide and straight enough for the feed material to flow easily into the digester. Slurry is *stirred* by inserting a long stick through the inlet pipe and agitating the digester contents with movements of the stick.

The Digester. Bacteria from the fermentation slurry produces biogas in the anaerobic conditions of the digester which holds 9.4 cubic metres of slurry. All other conditions being favourable, the amount of gas produced in the digester depends on the amount of time the slurry spends in the digester, called the *retention time* (RT). The longer the retention time, the more completely the slurry is digested, and the more gas produced. Retention time of slurry in the Sasse $9.4m^3$ digester is 90 days when 75 kg of fresh manure (plus 75 litres of water) are added daily.

The Sasse digester is constructed upon a shallow conical bottom slab with a hemispherical outer wall. The bottom slab distributes the weight of the digester over the site. The walls of the digester are spherical because such shapes use less building material, are less likely to crack, and are easier to build than angular (box) shapes.

(Example continued next page)

The Outlet. Fully digested effluent is displaced from the digester through the outlet by incoming slurry added through the inlet. As the level of the outlet pipe is slightly below the level of the inlet pipe, this is called *gravity* displacement.

The Gas Holder. Biogas is collected and stored until consumption in a specially-made floating drum called the *gas holder*. It floats atop the slurry as bubbles of biogas accumulate inside it. A central guide frame keeps the gas holder in place. As more gas accumulates, the gas holder rises on the central guide frame pipe. As gas is used, it sinks back down into the slurry.

The Sasse gas holder stores 1.8 m^3 of gas. It is constructed of thick steel sheets with welded-in braces. These braces break up surface scum and assist in agitation when the gas holder is rotated. The guide frame acts as an internal gas outlet (see diagram).

The gas holder must be completely gas-tight. Its top is slightly sloped to prevent rain from accumulating and causing rust. It is well-coated with paint (at least three coats), and repainted annually as rust will destroy the welding joints and cause gas leaks.

Biogas inside the gas collector is at atmospheric pressure (unlike LPG gas cylinders, which are at high pressure). The weight of the gas collector provides the pressure to push the gas through the pipes to the appliances.

The Water Trap. A water trap is placed at the gas pipe's lowest point to collect water that condenses in the pipes. Biogas contains water vapour. The underground gas piping is at a lower temperature than the gas holder so gas from the collector enters the underground piping and cools. As the gas cools, the vapour condenses. This liquid water will block the pipes if it is not removed.

Water formed by condensation collects in the U-shaped water trap located at *the lowest point* in the pipe and flows out of the system. Thus, the problem of water blocking the pipes is avoided.

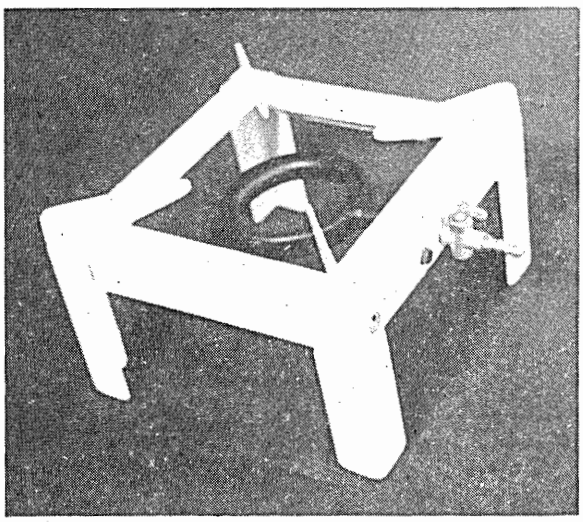
Gas Distribution and Uses. The gas pipes carry biogas from the gas collector to the place where it is consumed. Gas pipes may be made of steel, copper or PVC and are usually 1-2 cm in diameter. Underground piping is preferable because the pipes are thus protected from the sun, and they are less of a hazard or obstacle.

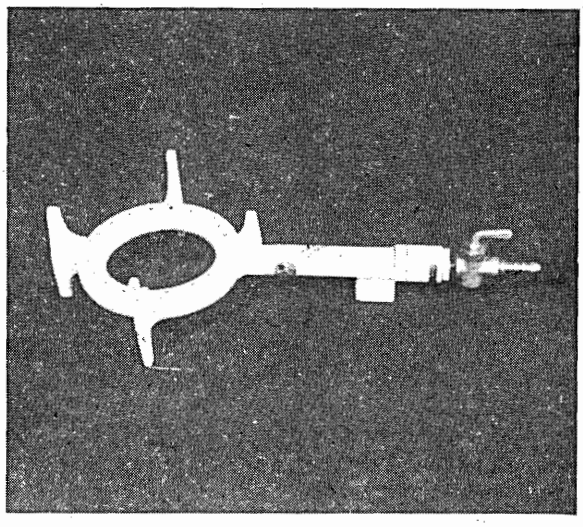
Biogas should be treated in the same way as any other combustible gas. When biogas is mixed with air in certain proportions (1:20), explosions may occur. However, biogas does have a mild odour which can alert users to leaks, and reports of explosions in biogas systems are rare, if not unheard of.

The most efficient way to easily use the gas is cooking. Biogas has a calorific value of 21.3 MJ (5.96kWh) per cubic metre. This is about the same amount of energy as contained in 0.8 kg of wood. However, wood cooks with about 12% efficiency while biogas cookers operate at 55% efficiency.

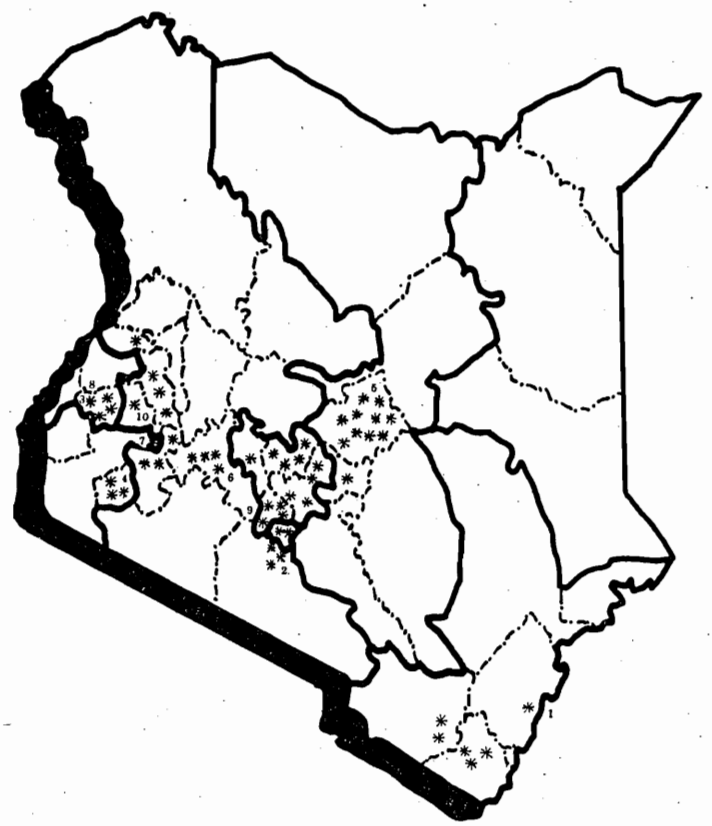
Biogas can also be used for lighting. Gas lamps with mantles produce light equivalent to that produced by 40 to 60 watt bulbs. It has also been used to run gas irons, water heaters, paraffin refrigerators and internal combustion engines. Diesel engines require a mixture of 90% biogas with 10% diesel oil to run properly, but spark engines (petrol) can be run on 100% biogas. In China, biogas is used to generate electricity in rural areas and to power farm machinery such as tractors and lorries. The use of biogas for transport is limited because of the difficulties associated with storing gas (2 cubic metres will carry a lorry about 5-6 km).

In Kenya, biogas is mostly used for cooking and lighting. Like digesters, the appliances for cooking and lighting must be well-designed and durable to be of any use. Quality cookers and lamps are presently manufactured locally. Several farms in Kenya currently power generators with biogas to meet their electric needs.





Biogas Digesters in Kenya

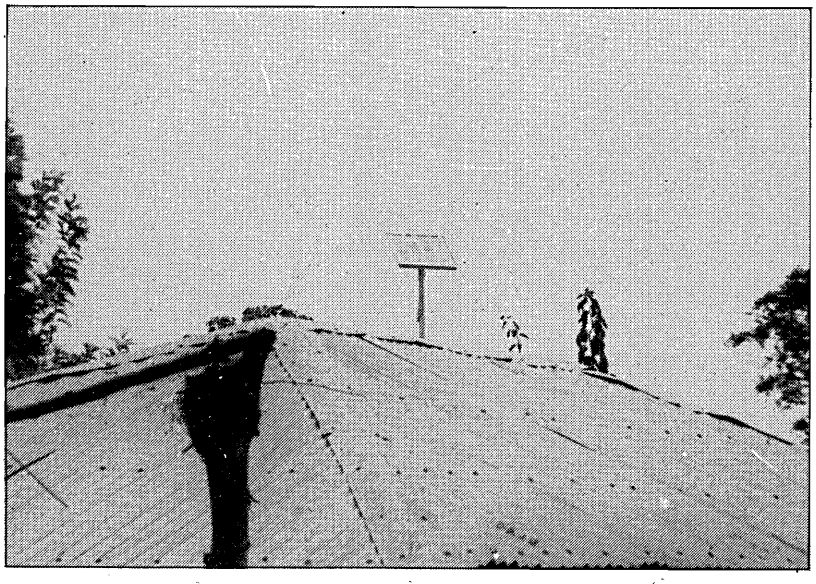


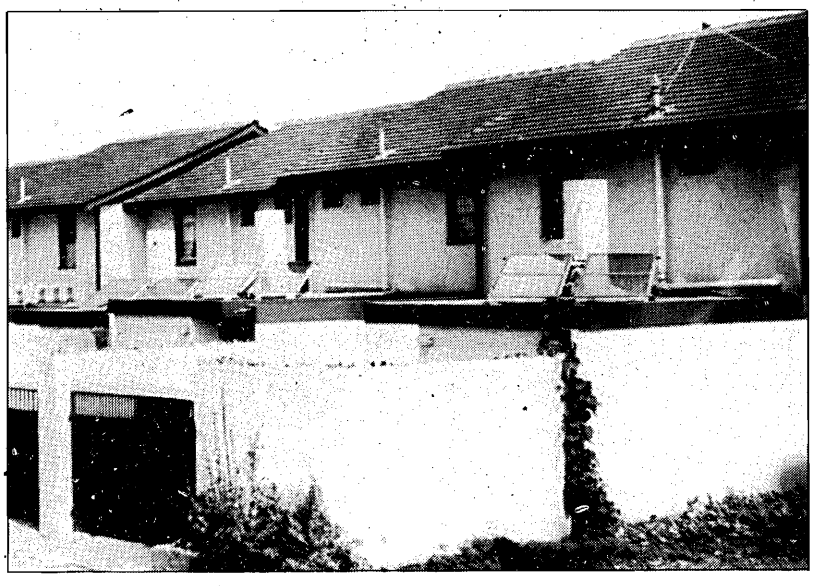
Legend

* 5 Biogas digesters

Example Biogas Sites

1) Mtwapa Agroforestry Centre (Sasse)
2) Jamhuri Agroforestry Centre (Sasse)
3) Bukura Agroforestry Centre (Sasse)
4) Kisii Agroforestry Centre (Sasse)
5) Kinoti farm, Mitunguu, Meru (Sasse)
6) Eaton farm, Nakuru (Sasse)
7) Koru/Ft. Ternan (Hutchinson)
8) Stephen Wanja farm, Kakamega (Hutchinson type)
9) Limuru Boys (Indian type)
10) Bor farm, Eldoret (Sasse)





Solar Energy 5

The Sun

Earth's nearest star, the sun, is its primary source of energy. The sun powers the cycles that produce hydro, wind, and biomass energy. Long ago, the sun provided the energy now stored in fossil fuels such as petroleum and coal.

Between eight and ten billion years old, the sun is predicted to go on shining for another four billion years. It gives off energy at a rate of 3.8×10^{23} kW, converting mass to energy (as happens in a nuclear reactor) at a rate of 4.7 million tonnes per second. Most of this energy is lost in space, but the tiny fraction that does reach the the earth is enough to provide all of our energy needs. It is high time we started making better use of solar energy.

About one third of the solar radiation that strikes the earth is reflected back out into space, and the rest is transmitted by the atmosphere. The total daily average of solar radiation that reaches the surface of the earth is 2.9×10^{16} kW/hours.

Solar Energy Availability

Scientists use the term *solar constant* to describe the amount of energy incident on a unit area (m^2) exposed to the sun's rays at the average sun-earth distance in the absence of the atmosphere. Put simply, this is the amount of solar radiation that strikes each unit area of the earth's atmosphere, or about 1400 watts per square metre at the edge of the earth's atmosphere.

The actual amount of energy received at ground level varies between almost 1000 watts/m^2 (mid-day at the equator) and zero watts/m^2 (at night). Northern countries (i.e. Europe) have lower solar radiation levels than equatorial countries because the incident angle of the sun's rays in the north is not perpendicular as it is at the equator. The normal angle of the sun's rays accounts for the intense solar radiation at the equator. The sunniest parts of the world, especially desert regions within the tropics, receive 7.2×10^7 kiloJoules per square metre (kJ/m^2) of solar radiation per year. Northern countries such as Britain, in contrast, receive only about 3.2×10^7 kJ/m^2 per year.

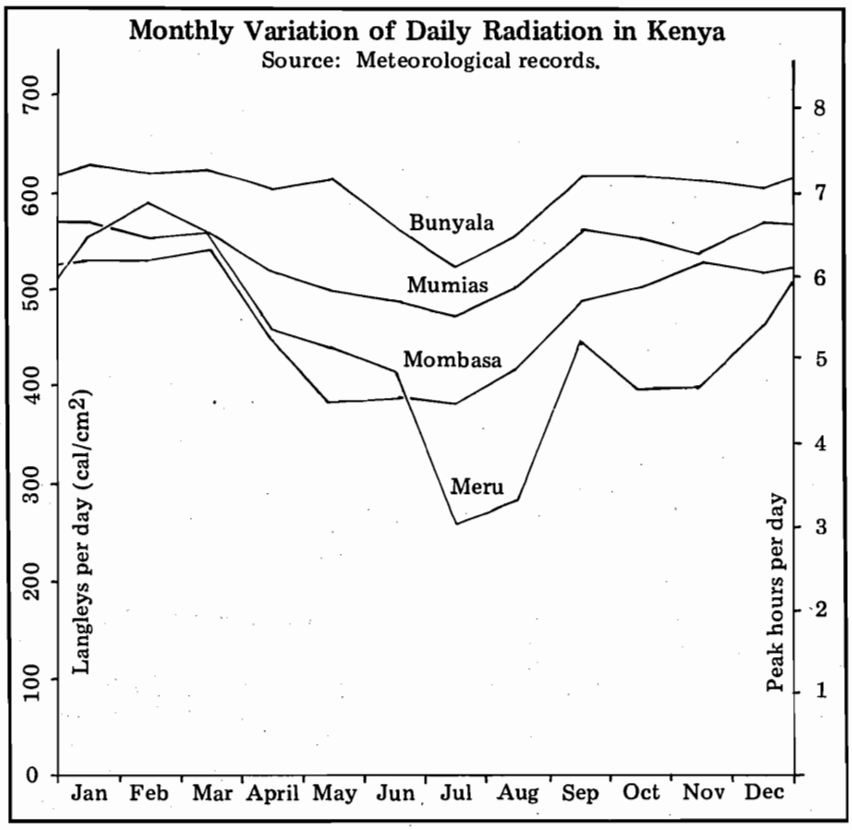
Useable solar radiation can be divided into *direct* solar radiation and *diffuse* solar radiation. Direct solar radiation, that which comes straight from the sun on clear days, has a high energy content which can be *focussed.* Diffuse solar radiation is radiation reflected by the atmosphere and clouds. Mainly a function of the amount of cloud cover, it reaches the ground from all directions. Diffuse radiation may aid low energy solar applications (i.e. solar water heaters), but it cannot be focussed.

Annual solar radiation is predictable. Factors which affect the amount of solar radiation an area receives include the area's *latitude, cloudy periods, humidity* and *atmospheric clarity.* At high-intensity solar regions near the equator, solar radiation is especially affected by cloudy periods. Long cloudy periods significantly reduce the amount of solar energy available. High humidity absorbs and hence reduces radiation. Atmospheric clarity, reduced by smoke, smog and dust, also effects incoming solar radiation. The total amount of solar energy that a location receives may vary from season to season, but is quite constant from year to year. The graph on the next page shows solar radiation data compiled by several meteorological stations in Kenya. In general, any area in Kenya can be considered a high potential solar area.

Using Solar Energy

Solar radiation is light energy. To make use of this energy, it must first be transformed into a useful form. Solar energy can be directly transformed into *chemical, heat* or *electrical* energy.

Of these three transformations, the most important is the one in which solar energy is changed into stored chemical energy. Living green plants store solar energy as chemical energy in sugar and cellulose by the process called photosynthesis. All biomass contains chemically stored solar energy. Man has not yet developed a way to directly transform solar energy into chemical energy and, since photosynthesis is a secret of green plants, it is not covered in this chapter (for more information on using biomass, see chapters 3 and 4).



However, man converts solar energy into heat energy and electrical energy using devices described in this chapter. Solar heating devices transform solar energy into heat which is used for drying, water heating, space heating, cooking and distilling water. Solar electric devices transform solar energy into electricity for lighting, powering radios, pumping water, etc.

Harnessing solar energy presents several problems. First, rather than arriving in concentrated amounts of high grade energy (as wind and hydropower often do), solar energy arrives spread over a wide area in a relatively low energy form. Secondly, solar energy is not available at night or during overcast and cloudy weather. Thirdly, the forms of energy derived from solar energy are difficult or expensive to store.

Solar energy is, therefore, most easily used in low energy applications. The cheapest and simplest uses of solar energy raise the temperature of air or water by 20-40°C (i.e. solar driers and water heaters). However, when high quality forms of energy are needed (such as high temperature or electricity), solar energy must usually be concentrated and/or stored. Increasing the quality of energy collected from the sun increases the cost and complexity of solar equipment needed.

Solar Energy Principles and Devices

This chapter describes the following general uses of solar energy:

-Drying crops or other materials
-Heating water
-Distillation of clean drinking water
-Cooking
-Generating electricity

It is important to note that the above applications are not the only uses of solar energy. They are included here because they have been successfully applied or have potential for widespread use in Kenya. However, there are other applications of solar energy which have been used historically, such as solar evaporation ponds long used at the coast for salt-making. Some experimental modern uses of solar energy are mentioned in the table below:

Table 5.1: Experimental Uses of Solar Energy

USE	METHOD	LOCATION
Refrigeration	Solar/freon refrigerators	Nyahururu, Kenya
Pasteurization of milk	Solar heaters	France
Steam raising in breweries	Solar collectors	Australia
Tobacco drying	Solar driers	Zimbabwe, Argentina
Distillation of wine process products	Solar stills	France
Steam engines for electrical generation	Solar concentrators	USA, France

Applications of solar energy must overcome its diffuse and periodic nature as well as the difficulties of storing it. Therefore, each device which harvests solar energy must apply such principles as concentration and absorption which are briefly described below. The special principles of solar cells are discussed in the solar electric section.

Concentrating Solar Energy

Solar concentrators and *reflectors* help overcome the spread out nature of solar energy. They collect solar radiation shining on a large area and reflect or focus it to a small area where it is trapped or harnessed at high temperatures. Concentrators make use of reflective surfaces and shapes (i.e. mirrors) which "bounce" radiation off their surfaces and direct it to a focal point. By covering a large area with solar concentrators, the total radiation that falls on that area can be focussed into a small area and absorbed as heat.

Parabolic concentrators like this model at Kenyatta University produce the high temperatures needed for cooking food.

Trapping Solar Energy

Solar energy is trapped using heat absorption principles and the *greenhouse effect* .

The Greenhouse Effect: Light radiation can pass through glass (or clear plastic) surfaces, but infra red energy (heat) cannot. Solar radiation thus passes through the glass windows of a solar collector, is absorbed by the surface behind the glass and reradiated as heat which *cannot pass through the glass.* This heat is trapped inside the solar collector.

Solar absorption: Solar radiation is absorbed on surfaces as heat. The amount of heat radiation absorbed depends upon the *area, colour and material of the surface* and the *angle of the incoming radiation.* Solar energy is best absorbed on surfaces which are perpendicular to the solar radiation.

Dark coloured (i.e.black) non-reflective metal surfaces absorb solar radiation most effectively. Solar water heaters, stills, driers and cookers make use of black painted absorber surfaces for trapping heat.

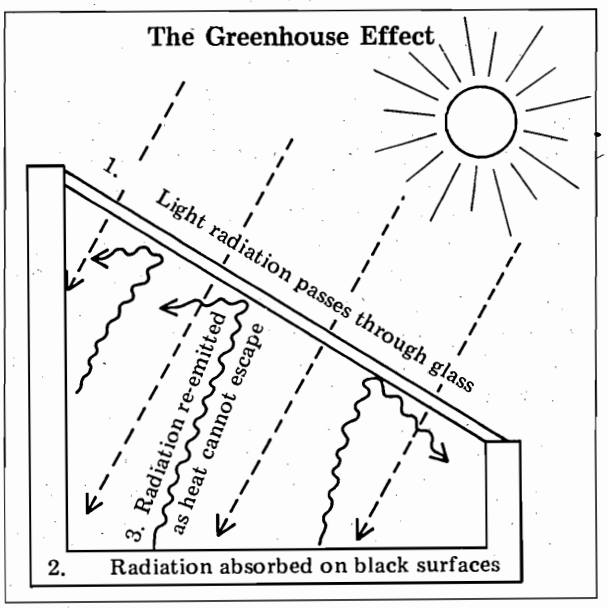
Flat plate collectors take advantage of both the greenhouse effect and absorption principles to trap solar energy. These solar collectors are large boxes with glass windows in front of an airspace and black metal absorber plates with a layer of insulation behind. Water heating collectors transfer heat from the absorber plate to water flowing through pipes attached to the absorber plate. Air heating collectors radiate heat from the absorber plate to air flowing through the airspace. (See also page 98).

Tracking: Making Best Use of Solar Energy

Turning solar devices to face the sun as it moves across the sky is called *tracking*. Because solar radiation is absorbed most effectively when it strikes the solar collecting devices at a right angle (90 degrees), more solar energy is absorbed when solar collectors track the sun. Sometimes it is effective to turn the solar device just a few times per day, and other times continuous tracking is necessary.

Tracking helps to offset the effects of periodic cloudy weather. If a location is cloudy at noon but sunny in the morning, a horizontally fixed solar device will not make best use of the sun as the morning sunshine will not strike at a right angle. By tracking, both morning and afternoon sunshine is effectively collected. Tracking increases the collected solar radiation significantly.

Tracking is often accomplished manually. For example, concentrating solar cookers are turned to face the sun frequently by the person cooking. Turning solar electric devices to face the sun several times per day increases solar energy collection by 30%. Tracking is used especially for solar cooking and electric devices (see photo page 107). Most solar devices with parabolic-shaped concentrators utilise tracking systems.



Solar Crop Driers

Drying of crops is a process by which moisture is removed from the crop product in order to prevent moulding and facilitate storage. Crop drying practices are used by every culture throughout the world, and solar energy plays an important role in traditional and modern crop drying methods. Maximum use of solar crop drying techniques and improved crop storage methods will help insure Kenya's future food self-sufficiency.

Traditional drying methods often expose crops to rain and pests.

Why Dry Crops?

Many small farmers do not store much of their *shamba's* harvest. Because they know that food quickly spoils, they store enough food to feed their family until the next harvest, and, quite often sell the rest to markets in town. During droughts, these people are left with little food to feed their families.

Farm produce that is properly stored can be eaten or sold during times of shortage. But in order for food to be properly stored it must first be prepared for storage. *Proper drying is the most important factor in determining whether a crop will be stored without damage.* Well-dried crops do not spoil easily.

Good crop driers and storage facilities help developing farm communities. With these devices, food losses are reduced. Farm incomes are increased as farmers sell stored grains for higher prices during dry seasons. Furthermore, crop driers and grain stores increase security because they insure the availability food even during drought seasons.

Crop Drying Methods

There are several methods by which farmers dry their crops. The most common is open air solar drying. Farmers leave crops (e.g. maize) standing in the field to partially dry and later spread them under the sun on trays or on the ground. This method cheaply uses plentiful solar energy. Some large farms and co-operatives use commercial crop driers which run on gas, oil, or woodfuels. Although these large gas-powered crop driers are expensive, they work even during cloudy weather and dry crops very thoroughly and evenly.

Traditional Crop and Food Drying

Solar drying is not new to East Africa. Traditional methods of drying and preserving foods make much use of direct solar and wind energy. In fact, solar energy is still the most important food preserving tool in Kenya. The traditional drying methods described below are still used today.

Cereals and legumes such as sorghum, millet, maize, peas and beans are left to partially dry in the fields after they have ripened and then, when the moisture content inside them is still high, they are harvested. After cleaning, they are placed on open mats or in shallow woven baskets and left in the sun to dry.

Certain fruits and tubers are also dried in the sun. In Western, Nyanza and Rift Valley Provinces, cassava is dried by the sun before it is ground and made into flour. The Banyole, and other Ugandan tribes, have long preserved bananas by peeling them, placing them on mats and leaving them in the sun to dry.

Fish and meat are also preserved using solar energy. Fishermen at the coast and along Lake Victoria place fresh fish atop their thatch roofs or on trays, and dry them during the day. At night, they move the dehydrated fish inside and place them above the fire where they are smoked. Animal skins are stretched and dried by solar energy. Soon after slaughtering, animal skins are staked out in the sun to be cured.

Fuelwood is also dried in the sun. After collecting bundles of wood, women lay it out in the sun to dry thoroughly. In fact, today, with the increasing wood scarcity, certain businessmen are purchasing wet wood cheaply, sun drying it in lots and selling it at higher prices to customers who need fuelwood.

Cash Crops and Solar Drying

Many of East Africa's important cash crops make use of solar drying during their processing. Coffee beans are dried in trays that expose them to solar radiation, convection currents and the wind. Pyrethrum is spread in the sun to dry soon after it is harvested from the fields. Solar drying is important in the processing of cashewnuts, macadamia and groundnuts. Spices such as nutmeg (one of the main export crops of Zanzibar) are also sundried.

Several local drying applications could switch to solar energy and save much woodfuel and petroleum. The tobacco industry, which uses great amounts of woodfuel during leaf curing, could reduce its reliance on wood by using solar driers. Zimbabwe's tobacco industry has successfully installed solar driers in its leaf curing operations.

At least one firm in Kenya uses conventionally powered driers to dry fruits such as pineapples, mangoes, coconuts and bananas for sale locally and for export. However, solar driers could make the process more profitable in the long term, as they eliminate the need for imported fuels and machines. Fruits are commercially solar dried by companies in Australia,

Israel, Saudi Arabia, Syria and the USA.

Solar drying is a large business. Transporting sun-dried fruits is cheaper than transporting fresh fruits because sun-dried fruits weigh less, take up less space, and are not likely to spoil. There are large markets for dried fruits in the Middle East, Europe and America. In 1968 alone, Australia exported 27 million dollars worth of solar-dried fruits.

Solar Crop Drying Benefits

Recent advances in solar crop drying technology can be used by both large and small-scale farmers. Improved solar driers are often simple: e.g. black plastic sheets spread on the ground for drying beans. They can also be complex: e.g. large, specially designed drying chambers in which the solar-heated air is pushed by electric fans through drying materials. Any improved solar drier offers one or more of the following advantages over traditional drying methods.

Solar driers:

Make better use of solar radiation than open air drying methods. Solar crop driers efficiently transform sunlight into heat energy which is then effectively used to heat air and dry crops.

Reduce crop spoilage by humidity, dust, insects, rodents, birds, wind and sudden rainfall. Traditional methods of direct open air drying leave crops in the fields where they are often destroyed by pests or unexpected weather changes. Improved solar driers enclose drying produce so that it cannot be attacked by outside vectors.

Produce high quality evenly dried products. Solar crop driers dry products thoroughly as they enable better control of the heat energy and drier ventilation.

Reduce drying time. Because solar driers efficiently capture and direct solar energy as heat through the drying produce, they dry crops more quickly.

Basic Principles of Solar Drying

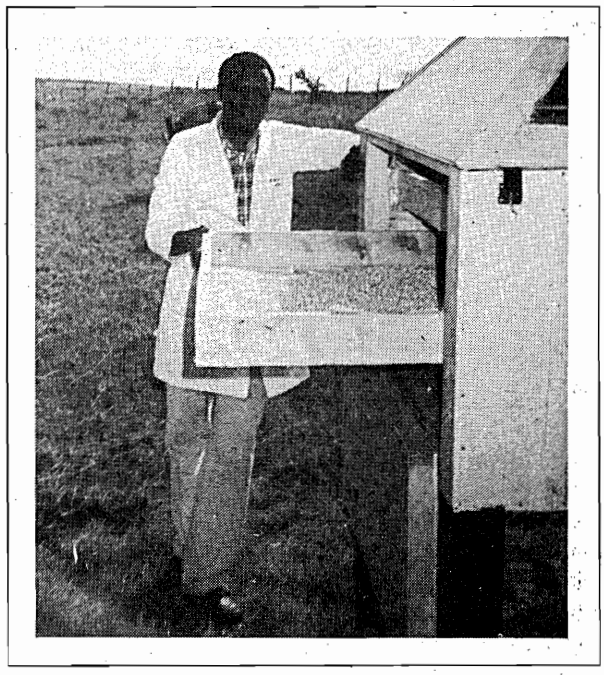
Solar driers heat air with collected solar radiation and use it to dry a product. There are two parts in the solar drying process. First, solar radiation is captured and used to heat air increasing its ability to hold and carry water vapour. The second part of the process is the actual *drying* during which heated air warms and extracts moisture from the product. Drying takes place in a large box called the *drying chamber*. Air is either heated in a *flat plate collector* or through a window in the drying chamber.

Solar Heating of Air

Air, the "working fluid" in solar driers, is used to move heat and moisture in and out of the drier. Having been heated by the sun, it is passed through the drying product at a low relative humidity. Hot air absorbs moisture from the drying produce and is vented out of the drying chamber at a higher humidity.

Simple crop dryers heat the air and product directly, and the solar collector and drying chamber are constructed as one box with a glass cover. Produce is dried in the chamber by both warm air and direct solar radiation. Other types of crop driers heat the crop indirectly. In these cases, air is first pre-heated in a flat plate solar collector and then passed into the drying chamber where it extracts moisture from the product.

Air moves through simple solar crop driers by *convection*. It enters the collector or drying chamber at the bottom, is heated, rises, and leaves the box through holes at the top. Large crop driers may use fans to move air through the produce if the convention rate is not fast enough.



This solar maize drier developed by Herick Othieno has been tested in Kitui and Western Province.

The Drying Process

Drying proceeds as heat is transferred to the surface of the moist product, causing water to evaporate from the product. Heat is transferred to the drying material by conduction and convection from surrounding air, conduction from heated surfaces in contact with the drying material, and by radiation from the sun and surrounding hot surfaces. The rate and completeness of the drying process depends on several factors:

- *Moisture content of the product.* Produce that has a high moisture content often takes longer to dry than produce with a low moisture content.

- *Air temperature and humidity.* High temperatures and low humidity speed up the drying rate. Humid air does not absorb as much water as dry air. Similarly, air at low temperatures does not absorb water as quickly as hot air.

- *Surface area of material.* Produce with a large surface area dries more quickly. Smaller pieces dry faster than larger pieces. Thinly sliced products dry faster than unsliced products.

- *Air flow rate.* The faster the air flow, the faster moisture is removed from the products, and the faster they dry. Properly designed solar driers have high natural convection rates. Often chimneys are used to speed up the air flow rate.

- *Type of product to be dried.* Different agricultural products dry at different rates depending on each product's moisture content and surface area, as described above. Also, the drying rate depends on each product's *porosity* (how fast moisture can escape from it) and the rate at which each product absorbs heat.

The fastest possible drying rate is usually desired. However, some products may be spoilt if they are dried at too high a temperature. A solar drier in India, for example, was meant to *dry* fish but *roasted* them instead. Therefore, the temperature of the solar drier should be adjusted for each product that is being dried.

Other products are spoilt by direct sunlight, and need to be dried in dark cabinets. Vegetables are bleached by sunlight and lose their taste. Therefore, some type of *indirect* solar drying is used to prevent solar radiation from damaging such produce.

Types of Solar Driers

Traditional Natural Solar Driers

The oldest and simplest types of solar driers, natural driers, place drying products on clean dry surfaces such as racks that expose them to sunlight and wind currents. Natural solar driers dry crops at the normal outside temperature and humidity as solar radiation and the wind combine to dehydrate the crop. Unlike improved solar driers, natural solar driers do not enclose the product.

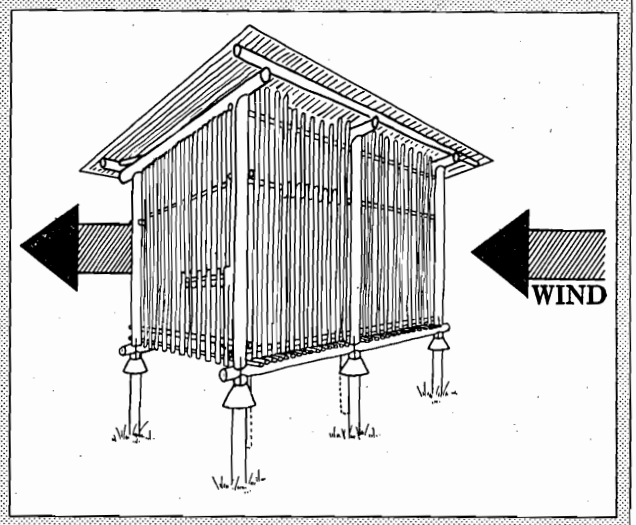
Advantages of natural solar dryers:

- They are cheap and can be made with local material.
- They use wind energy as well as solar during drying.
- They move the product off the ground and out of fields, preventing losses to pests and the weather.
- They can both store and preserve crops.

Natural solar driers are use extensively in Kenya, in such applications as traditional maize cribs and coffee drying racks.

Example: Maize Drying Storage Cribs

One local project of the Ministry of Agriculture and Livestock Development promotes maize drying storage bins for small farmers. The cribs, partially based on traditional granaries, both *dry* maize and *store* it out of reach of rain and rodents. The cribs are built off the ground with *ventilated* walls which allow wind to pass through. The wide part of the crib faces the prevailing wind and this forced convection (see figure), together with the solar radiation on the *mabati* roof, quickly dehydrates the maize harvest. Another feature of the cribs, which can be made completely from local materials, is ratguards under the support posts. This project was based in Maseno (through 1986) and supported by the United States Agency for International Development.



Direct Solar Driers

Direct solar driers are closed, insulated boxes inside which both solar collection and drying take place. Radiation is collected through a transparent cover in the drying chamber which contains trays to hold the drying product and vents through which air can enter and exit (see diagram next page).

Operation

1. Solar radiation passes through the transparent cover and is absorbed as heat by both the black painted surface and the drying product.

2. Radiated heat warms the air inside the box causing it to rise, and exit from the box at the top vents.

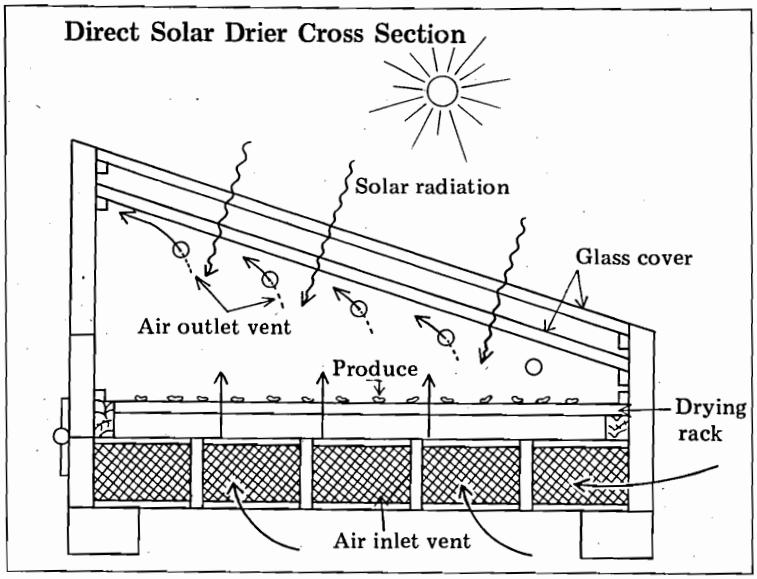
3. This convection current carries moisture evaporated from the drying product out through the top vent. Cool air replacing the warm air enters through vents on the bottom part of the box.

Advantages of direct solar driers:

- They operate at a higher temperatures than natural solar driers.
- They prevent attack by insects and micro-organisms because of their high temperature.
- They dry crops more quickly than natural driers.

Indirect Solar Driers

Because indirect solar driers have a flat plate collector and a separate drying chamber they operate more efficiently than direct solar driers. The solar



collector heats air causing a convection current which moves into the drying chamber through racks on which drying products are placed (see figure below).

Operation

1. Solar radiation is absorbed as heat energy by black metal absorber plates inside the solar collector.

2. The plates inside the solar collector radiate heat to the air inside the collector. This air expands and rises, creating a convection current of air moving into the drying chamber.

3. Warm air rising through the drying chamber extracts moisture from the produce on the drying trays.

4. The warm air continues to rise, carrying moisture with it, and exits through the chimney.

Advantages of indirect solar driers:

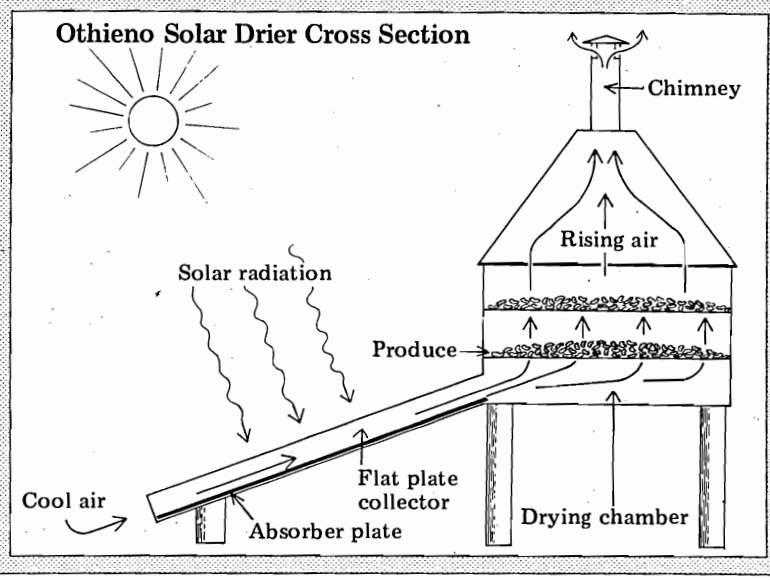
- Air passing through the solar collector is pre-heated (unlike direct solar driers).
- The rapid convection currents dry products faster than those in direct solar driers.
- Drying products (such as vegetables) are not damaged by direct solar radiation.

Example : Othieno Maize Drier

This solar maize drier (see also photo page 95), developed by Dr. Herick Othieno at the Kenyatta Appropriate Technology Centre, has potential to be used by many small-scale farmers in Kenya. Designed to reduce the moisture content in harvested maize from 20 to13%(wet basis), as of 1987, it was still being field tested in Kitui.

The drier consists of a flat plate collector (or *air heater*), an opaque crop bin and a chimney. The air heater is made from a black metal absorber plate with a glass cover. Mounted at a 20° angle, it creates a current of warm air that rises into the crop bin (drying chamber). The crop bin holds about 100 kg of maize in a wire mesh tray, and air rises through the tray and out the chimney.

During tests, the drier was found to work better than direct solar driers and traditional methods. However, initially, the air flow did not occur at a high enough rate through the crop bin, and this resulted in uneven drying of maize (the bottom layers dried faster than the top ones). Therefore, glass panels were added to the top part of the crop bin to allow solar radiation to enter and add heat to the chamber. The final design incorporates features of direct and indirect solar driers.



Both direct and indirect solar driers have several disadvantages over traditional solar drying methods. Unlike open air drying, they cost money and require special skills to build. Also, their use makes a major change in the traditional methods of harvesting and storing foods.

Effective use of *any* of the above solar drying methods has tremendous potential in Kenya. Drying fruits and grains which are plentiful during certain seasons but scarce during others creates a product that can be sold at any time. Well-dried produce has a long storage life, is easy to transport, and has definite markets. Kenya already has a proven capability of *producing* fruits, vegetables and grains. *Preserving* methods such as solar drying will help increase the country's food self-sufficiency and export capacity.

Solar Water Heaters

Solar water heaters are among the simplest applications of direct solar energy, transforming solar radiation into heat which is used to raise the temperature of water. This hot water is then stored in insulated tanks.

There is a great local need for hot water in hotels, industries, hospitals, schools and homes. Wood used for rural water heating is in short supply while boilers in many institutions use imported oil. Heating water with electricity is expensive, as often over half of an institution's or home's electricity bill is spent powering electric water heaters. Today, solar water heaters are replacing expensive and wasteful means of heating water, and because many are locally manufactured, they do not strain foreign cash reserves.

Parts of the Solar Water Heater

Thermosyphon solar water heaters are the most common type in Kenya. As they have no moving parts, the simplicity of their operation relies on the principle of *convection.* Heated water rises because it is less dense than cold water. A continuous *thermosyphon circulation* warms cold water, causes it to rise into a storage tank and replaces it with cool water from the bottom of the tank.

There are two main parts of thermosyphon solar water heating systems: the *flat plate solar collector* and the *hot water storage tank.* Flat plate collectors absorb solar radiation, transform it into heat energy, and conduct the heat into cold water that flows through the collector in pipes. Storage tanks insulate the hot water until it is needed. One pipe from the bottom of the storage tank (called the downcomer) circulates cold water into the flat plate collector. Another pipe (called the riser) circulates hot water from the collector to the top portion of the storage tank.

Flat Plate Solar Collectors

The function of solar collectors is to capture solar radiation as heat and transfer it into water. Basically, solar collectors are glass-covered flat boxes with attached metal absorber plates and pipes. Water flows through these pipes as it is warmed.

The cover (called *glazing*) is made of double-strength glass or clear plastic. It is fitted into the collector casing with rubber gaskets which provide room for the glass to expand as it gets hot and contract again as it cools. The glazing is sealed so heat cannot escape from the collector.

The *absorber plate* is made from metals with good conducting properties (i.e. copper, aluminium). Water pipes are attached directly to the absorber plate. Thermal conduction from the absorber plate to the pipes must be as high as possible for maximum efficiency. In order to get a good thermal bond between the pipes and the absorber plate, the water pipes are often sandwiched between two tightly pressed absorber plates. For good heat absorbtion, the plate is coated with black paint.

A casing holds the whole collector together and, with the glazing, makes it water and dust-proof. Water enters the collector through the downcomer and leaves through the riser outlet at the top. In Kenya, collectors are mounted at an angle of about 10 to 15 degrees, usually facing north.

Water Storage Tank and Piping

The cylindrically-shaped water storage tank is well insulated to avoid heat loss from the water. Its size depends on the area of the solar collector surface, the water temperature desired and the amount of water needed. Water storage tanks are mounted with their lowest point is at least 150 mm *above* the top of the solar collector. This allows water to flow at a maximum rate through the downcomer, collector and riser by convection.

There are three other pipes in solar water heating systems. A cold water inlet pipe brings cold water from the main water tank to the bottom part of the storage tank. The hot water outlet pipe conveys water from the top part of the tank to the hot water tap. The expansion pipe, which rises a few metres above the tank, is open to the atmosphere to allow water inside the tank to expand while heating without a dangerous pressure buildup.

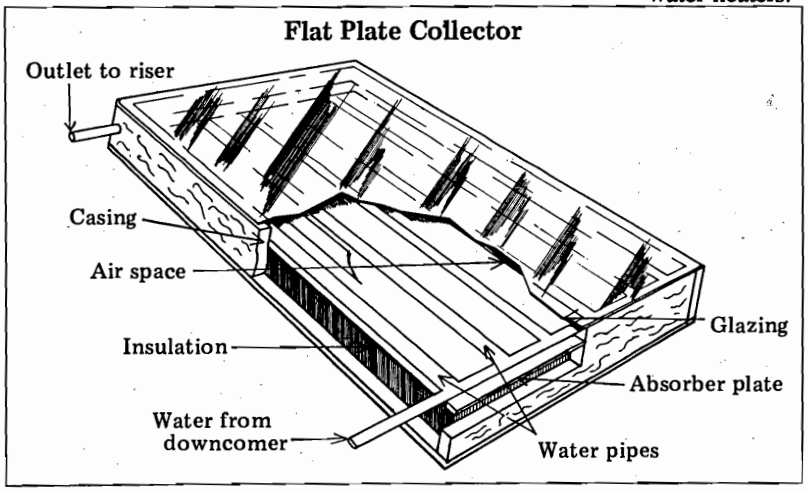
Operation of the Thermosyphon

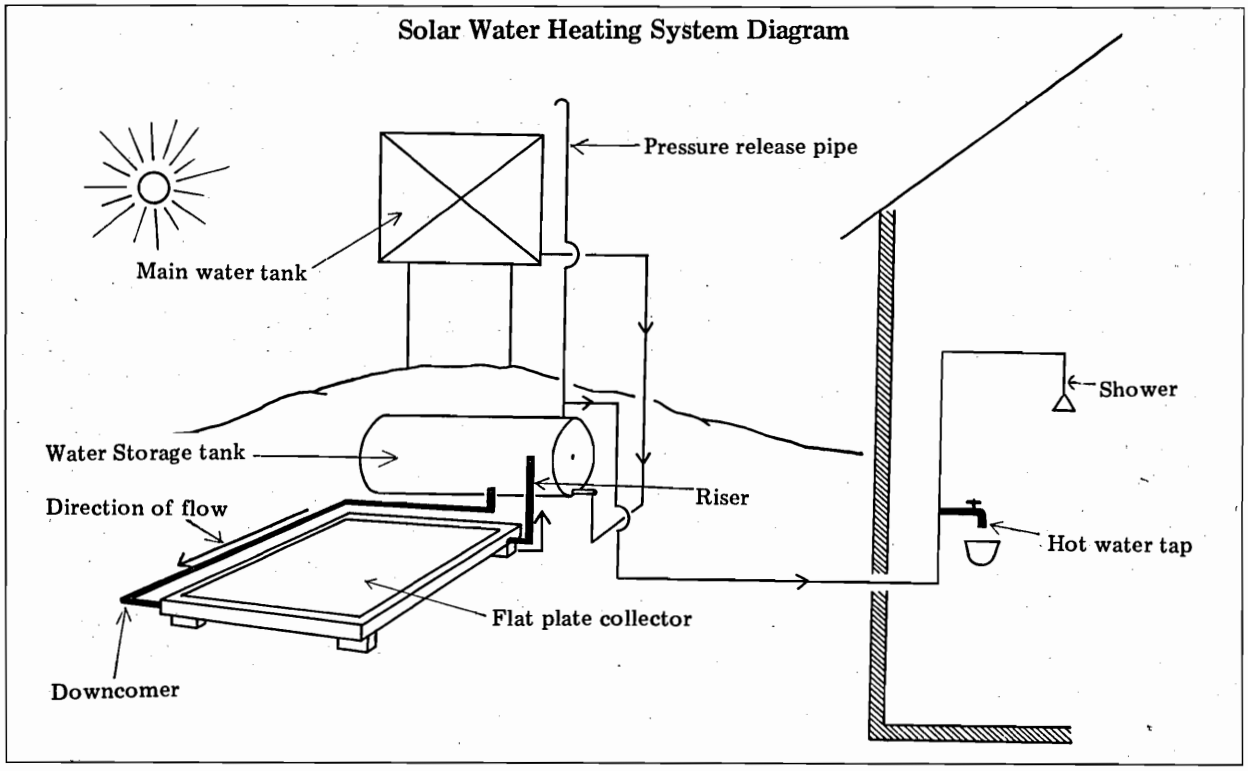
Several basic principles of physics are used by solar water heaters.

Collection of solar energy:
The Greenhouse Effect (see also page 93). Solar radiation passes through the glass cover of the collector and is transformed to heat on the black surface of the absorber plate.

Movement of heat into water:
Thermal Conduction. Heat always flows from areas of high temperature to areas of low temperature. The metal surface of the absorber plate conducts heat quickly into the metal water pipes. Heat then flows from the hot pipes into the cool water, raising the temperature of the water.

Flat Plate Collector





Movement of the water into the tank: Convection. Solar heated water in collectors moves slowly up through the riser pipe by convection at a rate that depends upon the amount of solar radiation. As hot water enters the top part of the storage tank, cool water flows into the collector through the downcomer.

Keeping the water hot: Insulation. Hot substances retain their heat longer when surrounded by insulating materials. The hot water storage tank and pipes are thus surrounded by good insulating materials to prevent heat loss by radiation.

History of Solar Water Heaters

Solar water heaters have been in use longer than any other modern solar technology. They were first developed and used in the southern parts of North America in the 1890s. Their use was widespread in California and Florida until cheap fuels (such as natural gas) became economical for heating water during the 1940s. However, after 1950, several countries without petroleum reserves continued developing solar water heaters.

By 1960, solar water heaters were being manufactured by several firms in Australia. The industry grew rapidly, and Australia now leads the world in production of solar water heaters, manufacturing 1.5 million units per year. In some northern districts of the country, almost all of the household hot water is supplied by solar energy. Throughout the Northern Territory, it is government policy to include solar water heaters in all government housing.

Companies in Israel have also been building solar water heaters for export and local use since the 1960s. More than 15,000 solar water heaters are produced per year in Israel and at least 20% of the country's population heats their household water with solar energy.

Japan has developed a simple, cheap design which combines heat collection and storage in the same thick pipes set behind glass glazing. Seventy five to two hundred litres of cold water are poured into the collector in the morning, and by late afternoon hot water is available for bathing and cleaning. Hundreds of thousands of households use solar water heaters in Japan.

Since the rise of petroleum prices in the 1970s, there has been a worldwide increase in sales of solar water heaters. They are once again becoming common in the USA, and there is an increasing market for them in Europe. Solar hot water heaters are also produced by growing numbers of companies in such countries as Nepal, Niger, Cyprus, Spain and Botswana.

Solar Water Heaters in Kenya

Solar water heaters *already* provide an important local renewable energy source as they have been in use in Kenya for at least 20 years. Mr. Hutchinson, also a local pioneer of biogas, was building solar water heaters during the 1960s while others were being imported from Australia or Israel. During the United Nations Energy Conference in Nairobi (1981), twenty companies acted as agents for solar water heaters and interest grew rapidly as more Kenyans realized the energy-saving potential of solar water heaters. The local companies producing these devices expanded rapidly after 1981. Today there are at least five companies manufacturing solar water heaters locally.

In 1985, the government allocated a significant amount of money to buy solar water heaters for government housing projects and these will save large

amounts of electrical power in urban areas. The biggest demand for solar water heaters, however, comes from home owners and hotels (most hotels in Kenya now use solar water heaters). As of January, 1986, there were between 14,000 and 18,000 square metres of installed solar collectors in the country. The market for solar water heaters is growing very fast.

Applications of Solar Water Heaters

Solar water heaters are ideal for remote locations because they require no fuel. They protect the environment because no trees need be cut down for wood when they are used. They save the government money as they use a local energy source. They fit a variety of situations, last a long time and require almost no maintenance.

Hotels use solar water heaters to meet the constant hot water requirements of tourists. Large arrays of solar collectors have been installed in most of the hotels along the coast, replacing electric heaters and diesel fired boilers. Remote game lodges in Maralal, Samburu and Masai Mara have replaced wood-fired heaters with solar collectors, saving both labour and wood.

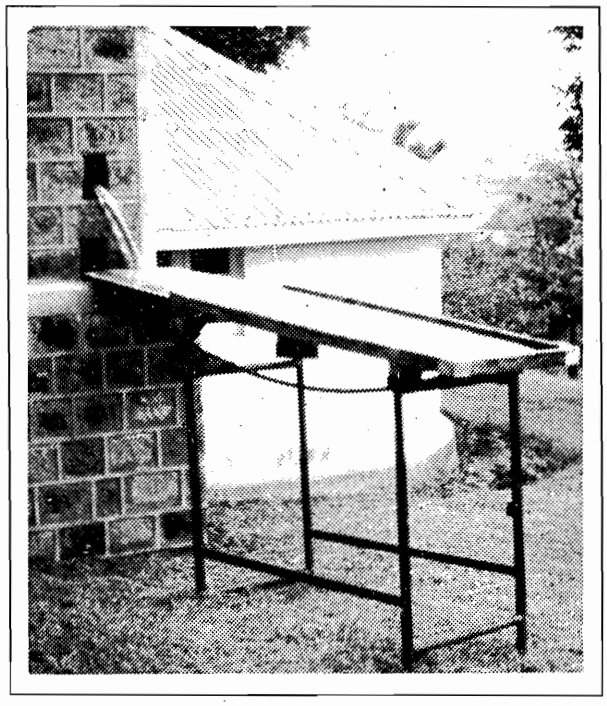
Hospitals are also using solar heated water. Hot water kills disease organisms and thus helps maintain a high sanitary standard in laundries, kitchens and showers. Hospitals in Meru and Western Kenya have installed solar water heaters and the Mariakani Veterinary Institute in Mombasa also makes use of solar heated water.

In homes and schools, hot water is required for bathing, cleaning utensils and washing laundry. Egerton Agricultural College and Utalii College use solar-heated water for their students' needs. There are 1000 solar water heaters in the Buru Buru housing estate outside Nairobi.

Small industries also meet their hot water needs with solar energy. An example of a cottage industry that uses solar water heating is Kibwezi Women's Group, which sells refined honey. The group uses solar heated water to seperate and purify honey which is then packaged and sold in various markets. At least one local tannery now uses solar heated water to process leather. The agricultural sector is beginning to use solar water heating. Dairies use hot water for sterilisation of containers, cleaning of *bomas* and cattle feed preparation.

Solar Cookers

Solar cookers collect and concentrate solar energy for use in preparing meals. Despite the fact that many designs work well in demonstrations, very few solar cookers are being used in Africa today. Most solar cookers require those who prepare meals to *change or learn new cooking habits* and this has blocked the spread of the technology. This section, therefore, presents working principles and models of solar cookers with hope that local pioneers will apply them to their own cooking needs.



Solar water heater in a home near Koru, Kericho.

Solar energy, unlike wood and petroleum products, is a plentiful source of cooking heat available freely and locally. Although it cannot cook food during cloudy weather or at night, it can replace a significant portion of the daily fuel need. Dry season sunshine at the Equator undoubtably has the *potential* to meet most of our cooking requirements.

History

Some of the first developments of solar cookers were carried out in Africa over 100 years ago. Auguste Mouchot, commissioned by Emperor Napoleon III of France, designed solar cookers for French troops stationed in North Africa. His design was one of the first *concentrator* type solar cookers which use a large bowl-shaped reflector to direct solar radiation onto a cooking pot.

Even before Mouchot's work, inventors in France and America had constructed working "solar box" cookers which, like solar driers, reflect radiation into a glass-covered black-painted box. In 1932 an Indian named Ghosh invented a *box cooker* made from a glass-covered insulated box and a single mirror. The Ghosh cooker is still used in India and cookers similar to it are now being mass produced there. Cheap, box-type cooker designs work well and seem to have the most potential for widespread use. Indeed, the Indian sub-continent (with its critical wood shortages) is where most development of solar cookers has taken place, and there are now thousands of people using solar cookers.

Large, institutional-type solar cookers which use flat plate collectors to trap and transfer heat to kitchens have been developed, along with hundreds of combinations of the two designs described here. A wide variety of designs are available to transform the 1000 watts/m^3 of equatorial sunshine into heat energy for

cooking. However, much work needs to be done *disseminating* the successful designs to areas where they can be used effectively.

The main advantage of solar cookers, that they *make use of Africa's most abundant energy resource, the sun,* must be weighed against several disadvantages. With most solar cookers, food can only be cooked during the hottest parts of the day and only on sunny days. Also, food takes longer to cook with most solar cookers.

Types of Solar Cookers

Solar cookers can be divided into two general groups:

Direct solar cookers use parabolic reflectors to concentrate solar energy at a focal point. Pots of food are placed atop the hot focal point and cooked by the concentrated direct solar energy.

Indirect solar cookers are insulated boxes with large glass windows into which solar energy is reflected and trapped. Cooking food is placed *inside* this type of cooker.

Direct Solar Cookers

Direct cookers concentrate and focus solar energy as heat onto food being cooked. Using a magnifying glass, one can focus and concentrate solar energy on a piece of paper and burn a hole right through it. In the same way, direct solar cookers collect all of the solar energy falling on a reflective surface (called a *concentrator*) and focus it onto a pot of food. Three important principles used in the design of solar cookers are *reflection, concentration* and *absorption.*

Reflection. The concentrator surface is made from a material that reflects solar radiation. Materials used as reflective surfaces include electroplated silver (used to make mirrors), high purity aluminium, aluminium foil and polished stainless steel.

Concentration of solar energy is accomplished by the concentrator. This device is located below the cooking vessel and shaped so that most of the sunlight striking its surface is reflected onto the bottom of the cooking vessel. Concentrators usually have a parabolic (bowl) shape which, when pointed directly at the sun, reflects solar energy onto a *focal point.* One cooker design uses several rows of concave mirror concentrators to focus heat energy onto the pan. A 1 m^2 concentrator with a good reflective surface can deliver more than 400-600 watts of heat energy to the cooking vessel under a clear, sunny sky.

Absorption of heat energy for cooking occurs at the vessel suspended over the focal point by a metal rod or grill. In order for it to absorb a maximum of heat, the cooking pot is blackened on the side where the reflected solar energy strikes it.

Operation

Food is placed in the cooking vessel during operation, the vessel is placed on the cooker grill and the concentrator is adjusted to direct the sun's rays onto the pot. If the concentrator is properly oriented, the cooking vessel's bottom immediately heats up. The concentrator is re-adjusted to face the sun every 15-20 minutes as the sun moves across the sky. Direct solar cookers produce temperatures high enough to roast or fry. Water reaches a boiling point as fast as with conventional cookers. Under sunny, clear skies, food is cooked quickly and easily.

Direct solar cookers have several disadvantages. There is a hazardous glare at the focal point, requiring the cook to wear sunglasses to protect her eyes. The concentrator must be adjusted to track the sun frequently, and the food must be attended as with conventional cookers. All of these activities must thus be done outside. On windy, hazy or dusty days, the performance of the cooker is significantly reduced. Even on clear days cooking will stop when a cloud blocks the sun, making it difficult to control the temperature of the cooking food. Concentrator cooker models are on display at Kenyatta Appropriate Technology Centre and Karen.

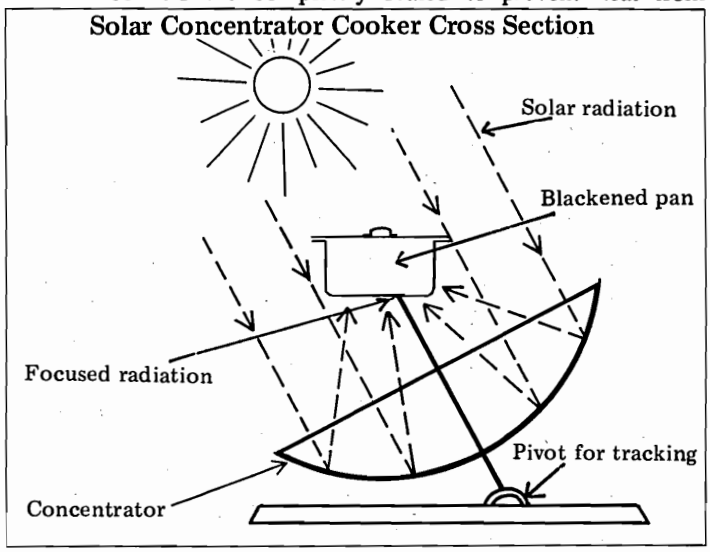
Indirect Solar Cookers

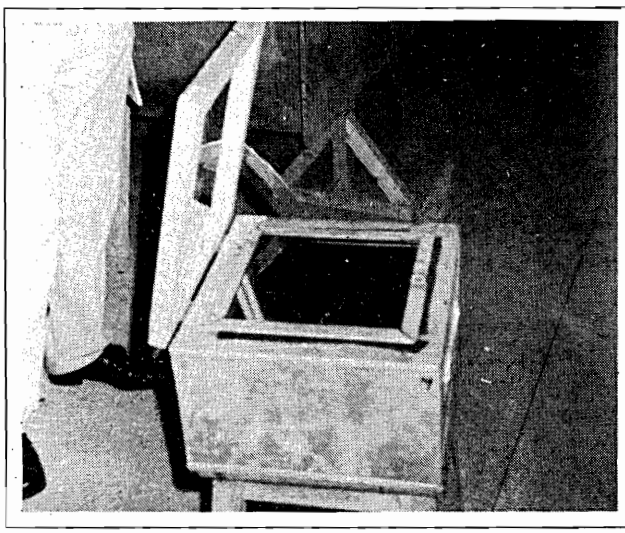
Also called *hot boxes* or *box-type* cookers, these are the most simple and successful solar cookers. Box-type cookers use plane reflectors (i.e. mirrors) to reflect radiation through a glass window into an insulated cooking box. Indirect cookers rely on the principles of *reflection,* the *greenhouse effect, absorption* and *insulation* during operation.

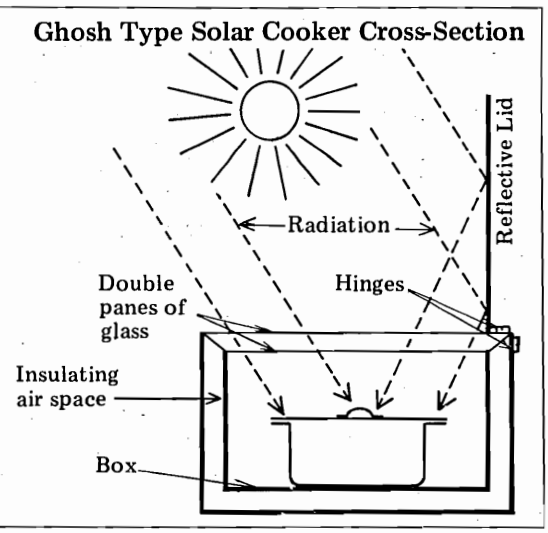
Radiation is reflected into box cookers by one or more flat reflectors attached at a 60^0 angle to the outside of the cookers. The more mirrors, the more radiation reflected into the cooker. Unlike concentrators, these mirrors are fixed and do not have to be adjusted to track the sun.

Like solar driers, solar box cookers make use of the *greenhouse effect* to trap heat behind the glass window inside the box which is painted black to increase heat *absorption.* Unlike solar driers, box cookers are completely sealed to prevent heat from

Solar Concentrator Cooker Cross Section







escaping. In addition, solar box cookers are thickly *insulated* with a suitable material which allows them to effectively *retain* heat energy.

Ghosh Cooker. The solar hot box built by Ghosh in 1932 is made of a large box containing a black-painted smaller box which is the cooking space. The air space between the two boxes serves as insulation to prevent heat escape. A double pane of glass covering the box opening increases the insulation effectiveness. The original design used one flat mirror to reflect radiation into the box through the window, but more mirrors can be added to increase the cooker's heat-capturing effectiveness.

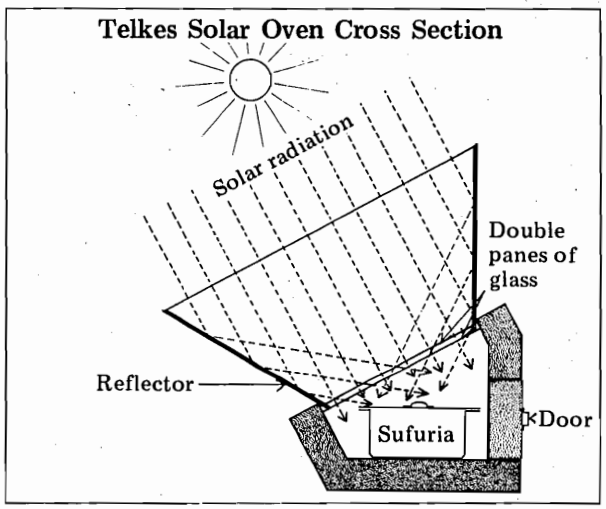
Food is placed inside the smaller box by opening the hinged window. When the window is again closed and the cooker is placed so that it faces the sun, the inside cooking temperature may rise above 160°C. Ghosh cookers are built cheaply from metal, wood, glass, black paint and small hardware items.

Telkes Solar Oven. This is an example of a more advanced indirect solar cooker. It is a large, heavily insulated, rounded oven with double paned glass windows which prevent heat loss. As there is more space inside the Telkes solar oven than in other hot boxes, it can cook several dishes at once. The oven has four large plane reflectors which capture and reflect much more solar radiation into the box than the single mirror of the Ghosh hot box. It may be mounted on a pivot to allow solar tracking for more effective results.

Hot boxes are best used for slow-cooking meals (such as *githeri*). They also allow baking of bread and cakes. Other foods such as stews, porridge and rice dishes cook well in box cookers. Their operation requires little attention, and food can be left cooking in the box while other tasks are given attention.

Box cookers have several advantages which have led to their mass production in India. As mentioned above, operation is easy. Unlike direct solar cookers, box cookers do not need to be adjusted to track the sun. Wind has no effect on solar box cookers because the cooking vessel is *inside* the insulated oven. As box cookers retain heat, food left inside them stays warm even after the sun sets.

As with other solar cookers, box cookers can only cook food between 9.00 a.m. and 3.00 p.m. On cloudy days another method of cooking must be used. Furthermore, there is a limit to the variety of meals that can be cooked in solar box cookers. Because they do not get hot enough, box cookers cannot fry or roast foods, and drinks take a very long time to boil.



Solar Stills

Solar stills use solar energy to produce safe drinking water from brackish, polluted or saline sources of water and are best applied in places where the water supply is unfit to drink.

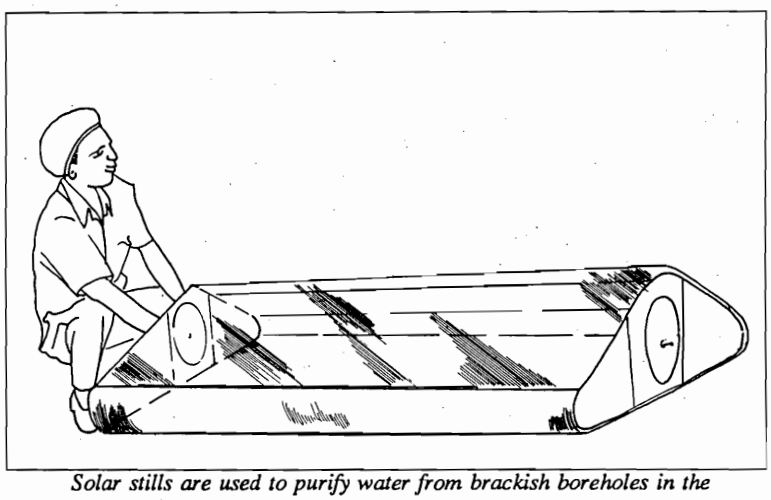
Application of Solar Stills

The first solar still was built in the Andes mountains (Chile) near a salt mine over a century ago. The mine's water supply was salty, so drinking water had to be carried to the camp from far away by animals. J. Harding built a 4,500 m^2 solar still of glass and wood that distilled 22,500 litres of fresh water per day. The still operated for thirty years.

An 8,800 m^2 solar still operation supplies drinking water to a community on Patomos, an eastern Greek island without fresh water supplies. A 3,530 m^2

operation supplies fresh water from a brackish well in Coober Pedy, Australia. Smaller solar stills are being built in such locations as the Kalahari desert in Botswana to provide fresh water from salty boreholes for the Basarwa people.

Solar stills are used during emergencies by people stranded in the desert or ocean. Water condenses on the underside of plastic sheets spread over holes in the desert sun, and if collected, is quite drinkable. Water will also condense on the underside of plastic sheets spread over trays of salt water and left in the sun (Similarly, the Maasai collect water in the Rift Valley by placing metal sheets over steam vents and collecting the condensed vapour).



Solar stills are used to purify water from brackish boreholes in the Kalahari desert.

Solar Still Operation

1. Solar radiation enters the still through the glass roof, heating water in a shallow tray by the *greenhouse effect.*

2. The temperature inside the still rises and water *evaporates* into the warm air.

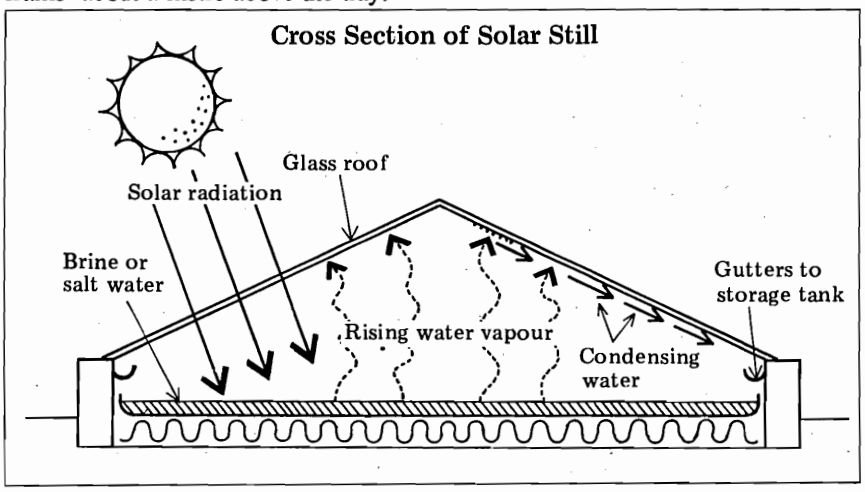
3. Water vapour comes in contact with the cool inner surface of the glass roof and *condenses* on the glass as a thin film.

4. Distilled water flows down along the slanted glass and collects in a gutter which carries it to a water storage tank.

Solar Still Construction

Solar stills are simple structures that look like small low houses with glass roofs. Inside the still is a shallow, black-painted tray which contains the brackish or salt water. This water is about 8-15 cm deep in a tray made of concrete, wood or some non-corrosive metal.

Glass or clear plastic roofs are supported by a frame about a metre above the tray.



Below the edge of the slanting glass are gutters which collect the distilled water and carry it to the water storage tank. Note that by putting gutters on the outside of the glass roofs, solar stills can also act as rain catchment devices. During rainy weather, when water is not being distilled, captured rain water can replace the distilled water.

Solar Still Output and Maintenance

A large area of solar stills is required to distill large amounts of drinking water. A still with 1 m^2 of glass roof produces about 4 litres of water per day during sunny weather. In order to produce 100 litres of water per day , a solar still of approximately 25 m^2 is required.

The water from a solar still, like rainwater, is quite drinkable. However, because it does not contain dissolved minerals, it is not as healthy as water from a river or well. Usually, a small amount of salt is added to the water (from the residue in the tray) to supply important minerals.

Solar stills require very little maintenance. Water must be added everyday to replace that water which has been distilled. Also, the salt or solid residue in the trays must be regularly washed out. The glass roofs need only to have dust and salt build-up removed from their surfaces occasionally.

Solar stills are most economical for applications which need small to medium amounts of water each day. Remote industries, schools, hospitals and communities near the ocean or contaminated water supplies make the best use of solar stills. The size of solar still needed depends on:

- amount of solar radiation,
- amount of water actually needed,
- amount of land and money available for building the still,
- rainfall contribution to the collected water,
- amount of water storage.

Solar Electricity

Solar electric (also *photovoltaic*) devices convert light energy into electrical energy. Although quite new, this technology is rapidly becoming an important source of electricity for remote areas around the world.

As demand for electricity increases in remote rural areas, solar electricity has begun to fill important roles in areas not yet served by Kenya's electric grid. Schools, hospitals and homes need efficient electric lighting. Dispensaries require refrigeration for important vaccines and drugs. Remote police stations and game parks must have electric power for their crucial communication equipment.

The Photo-Electric Effect

When certain substances are exposed to sunlight, they produce a measurable electric current. These substances are said to demonstrate the *photo-electric effect*. In 1839, a French scientist named Edmund Becquerel first discovered the photo-electric effect in a "wet cell" battery. Later, other scientists found that substances such as selenium and copper oxide produce small electric currents when illuminated by sunlight. However, as these processes were inefficient and expensive, *solar cells* were not considered as an energy source until over one hundred years later.

During 1954, scientists in the USA developed a way to treat very pure silicon so that it would convert sunlight to electricity with an efficiency of 6 %, a conversion efficiency ten times higher than scientists had been able to attain previously. When the U.S. space programme needed a way to generate power for the electrical instruments in space satellites, they turned to the scientists developing silicon solar cells. Soon, solar cells were being produced in large numbers and today, all space satellites are powered by solar cells, including those used for international telephone and television broadcasts.

Solar Cells

Solar cells are thin flat pieces of very pure silicon. They are cut into various shapes and sizes, ranging from the small square cells that power "solar calculators" to standard sized 9 cm diameter circular cells. Both sides of each solar cell have an electrical contact. The side exposed to the sun has a network of metal lines that act as the positive contact while the back side is coated with a solid layer of metal that acts as the negative contact. Because they are made of very thin slices of a glass-like material, solar cells are very easily broken.

All solar cells, no matter how large, produce electricity at about the same voltage; 0.4 volts. The amperage of a solar cell, however, depends on its size and on the amount of sunshine. Solar cells produce higher amperages as they increase in size or as the intensity of the sun increases. Under bright sunlight, one standard 9 cm diameter solar cell produces about 2 amps of current at 0.4 volts (with an optimum load).

Single solar cells are not very useful because their voltage and power output is low. But placing many solar cells in series increases the voltage and electric power available. Since each cell has a voltage of 0.4 volts, two solar cells in series have a voltage of 0.8 volts and ten solar cells in series have a voltage of 4.0 volts.

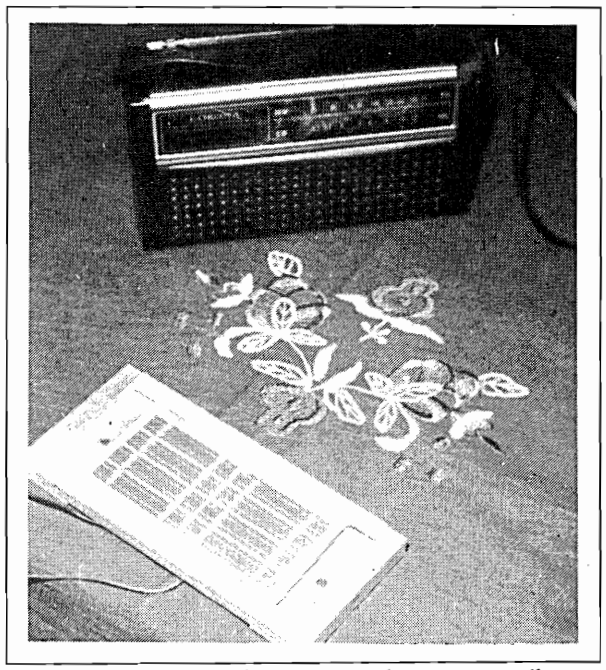
The photo-electric effect involves the direct transformation of light energy into electrical energy. Even with the most advanced solar cells today, light energy is changed into electricity at an efficiency of only 10 %. Stated simply, the process can be explained as follows:

Sunshine, coming in bundles of high energy particles called *photons*, strikes the front of the silicon cell. Incoming photons dislodge electrons in the outer orbit of silicon atoms from their bonds and these free electrons migrate across an electric field (a layer of impurities in the cell called the p - n junction) to the backside of the cell. As long as the sun is shining, electrons continuously migrate to the back side of the cell, giving it a negative charge. When a load is attached by wires to the front (positive) and back (negative) contacts, an electric current flows from the cell through the wires.

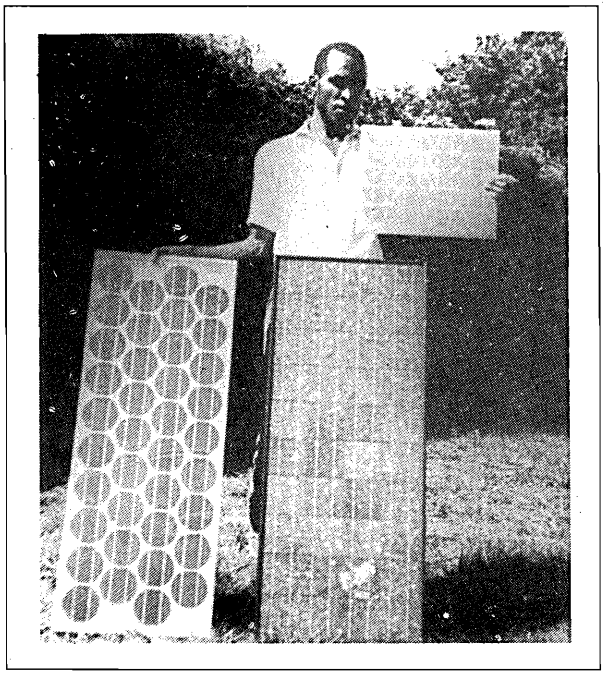
Solid state devices with no moving parts, solar cells are quite reliable. Solar electric equipment can be expected to last twenty years or more (according to the lifetime of the protective casings which enclose the cells) because sunlight does not damage the silicon material from which cells are made.

Solar Cell Modules

Fragile solar cells are always protected against breakage by carefully encasing them. A number of cells are usually connected in series and encased together to produce a usable voltage. Groups of solar cells connected in series and protected in glass and plastic



Several solar cells in series can be used to power small radios or calculators.



Three different sizes of solar cell modules.

frames are called *solar cell modules.*

Solar cell modules are available in various sizes, depending on the intended application. Standard 35 watt modules contain between 32 and 36 solar cells and produce 12 volts of current usually used for charging lead-acid batteries. This electricity is different from mains electricity in two ways. First, it is at a low voltage (i.e. 12 volts), as opposed to mains electricity which is 240 volts. Secondly, solar cells produce *direct current* (DC) which is different from the alternating current (AC) carried by the mains.

Solar cells are encased in modules because they are subject to decomposition upon exposure to water vapour and because they are fragile. A process called *encapsulation* seals solar cells in a vacuum between thick glass and plastic. The thick glass on the frame of the module is specially made to resist breakage and to let a maximum amount of sunlight pass through. The plastic behind the solar cells radiates heat so that the cells do not become too hot. The glass and plastic assembly is held inside a strong metal frame that keeps the module rigid. Behind the module, there are positive and negative contacts for attachment of loads to the solar cells in series.

The electric output of solar cell modules is affected by changes in the weather. Extreme heat or very cloudy weather lower the amount of electricity "harvested". Solar cell modules function best when they are kept as cool as possible. After reaching temperatures above 40°C their output decreases significantly and, for this reason, solar cell modules should never be mounted directly on tin (*mabati*) rooftops. During very cloudy weather, the output of a module drops to about a third of its sunny weather electrical output. Therefore, those who use solar electricity should reduce their electrical consumption during cloudy weather.

Solar cell modules are very durable, continuing to produce electricity for twenty years or more provided they are kept clean and safe. The glass front of a solar cell module is built to withstand such harsh weather conditions as hail and heat. However, modules should always be fixed where flying objects (such as footballs) cannot easily reach them.

Solar cell modules are mounted to receive maximum exposure to the sun, away from tall trees and buildings which cause shadows. They are fixed high enough off the ground to be above the reach of animals and people and attached to sturdy objects (i.e. poles) where they can be easily reached for cleaning. Groups of several or many modules mounted together are called *arrays.*

Tracking, a technique of *following* the sun as it moves across the sky during the day (see photo page 107), is often used to make maximum use of solar electric equipment. A simple, manually-operated tracking mount can increase an array's yield of harvested electricity by 30% or more per day.

Other Parts of a Solar Electric System

Batteries: Storing the Electric Energy

Because electricity is needed at times when the sun is *not* shining, most solar electric systems require a way to store the electricity. Lead-acid batteries (accumulators) are the most widely used devices for storing electrical energy. They store electricity in a chemical form that is available for night-time and cloudy weather applications.

Solar cell modules charge batteries during the day, and the charged batteries power lights and household appliances at night. Although 12 volt lead-acid car batteries can be used in solar electric systems, *heavy duty* batteries (available in Nairobi) which can stand many deep discharges will last much longer. Usually there is one battery for each standard solar cell module in a system. Batteries should be maintained to maximise their life performance.

System Control

Solar electric systems require some type of control so that the electric output can be monitored and regulated. A *control panel* has various features which protect the modules and the batteries such as master switches and fuses which reduce danger of short circuits. The control panel also prevents the system's batteries from being over-charged or excessively discharged. The panel may also have meters or lights which show whether the solar modules are working properly.

Applications of Solar Electricity

Solar electricity is appropriate for rural areas. Solar cell modules generate power at the place where it is needed enabling thousands of households far from the power lines to use electric appliances. Solar cell modules are reliable. As long as there is sunshine, they quietly produce an electric current. Solar electricity is most economical when supplying small amounts of power for lights, radios, televisions and small machines.

Small Applications (0.01 W - 35 W)

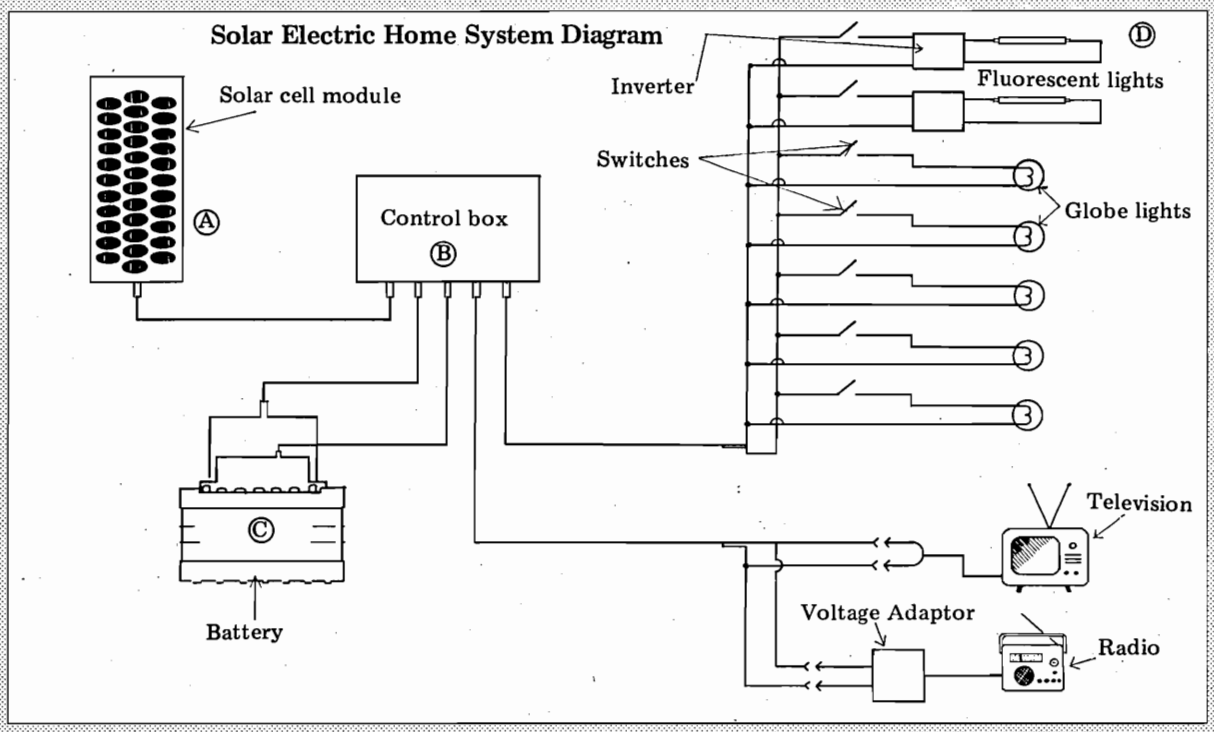
Tiny arrays of solar cells power electric calculators. Small solar cell modules (ranging from 2 to 15 watts) are used to re-charge batteries for radios or cassette players. Electric fences are also powered by small-sized modules. One standard 35 watt module will provide enough electricity for the lights, radios, television and small appliances in a typical Kenyan residence. A single standard module can power a tailoring business's electric sewing machine, with enough extra power for lights and a radio.

Medium-sized Applications (two to six 35W Modules)

A small array of solar cell modules provides useful electricity for small institutions and organisations. Classrooms in a small boarding school can be lit with power from several standard modules. Refrigerators in small dispensaries can be powered by 4 to 6 standard solar modules. Six modules can provide power for a small *posho* mill or water pump.

Example : A Solar Electric Home System

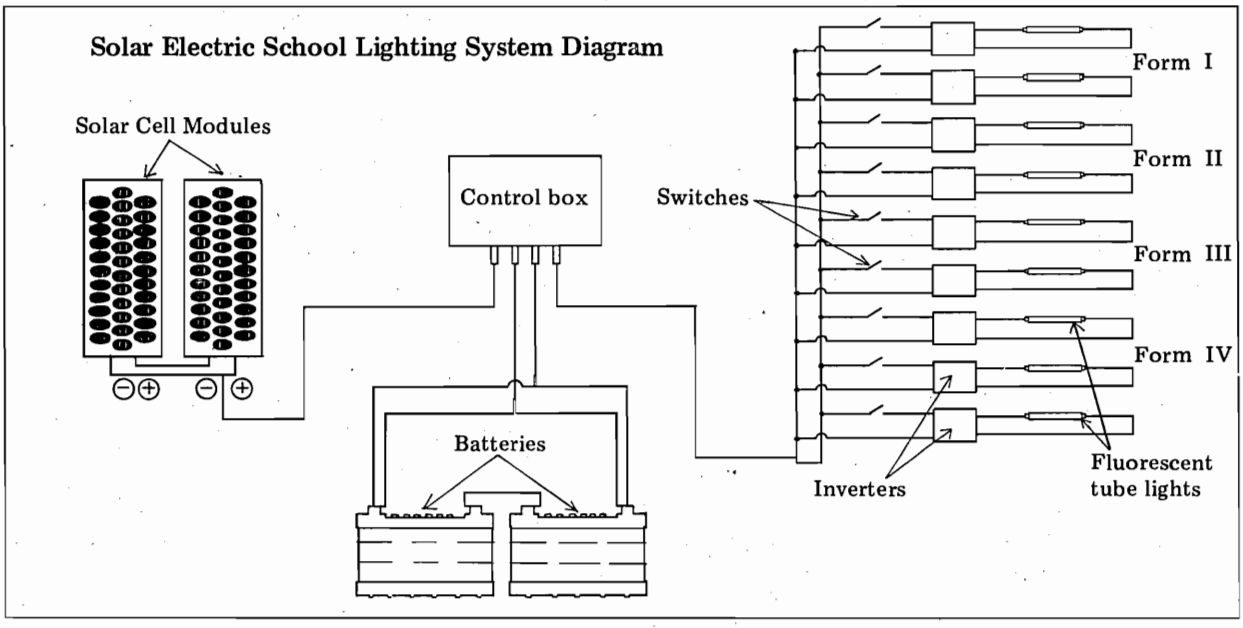
At least 500 rural Kenyan homes are now using 12 volt solar electric systems like the one described below. Most often, one 35 watt solar cell module (A) is used to meet the power needs of the household. It is mounted in a secure place (such as on a pole above the roof, but *never* directly on the *mabati*) and connected by wires to the control box (B). The control box regulates the electric power from the solar modules and uses it to charge one or more batteries(C). Lead-acid batteries for solar applications are made by at least one company in Nairobi, but any functional car battery will work provided it is maintained. Power from the batteries is regulated (to prevent them from being completely discharged) and fused through the control box before going to the appliances. In order to get the most economical use from the solar electric power, efficient fluorescent tube lights(D) are installed in rooms where light is most needed. Solar electricity cannot cheaply be used for cooking or heating.



Example : Solar Electric Lights for Boarding Schools

Solar electric lighting has proven to be quite practical for rural schools located far from the grid. Quiet operation, low maintenance requirements, adaptability and low first costs have convinced many schools to choose solar electric lighting systems.

A system developed especially for *harambee* schools in Kenya by *Solar Shamba* , a local company working with renewable energies, has been rapidly adopted by schools across the country. Because of the relative high cost of solar equipment, the company devised ways of using solar power as efficiently as possible. First, solar cell modules are fixed to *tracking mounts* (see photo next page) which collect 30% more power than flat mounted modules. The tracking mount, partially designed by Undugu Society, enables four modules to do the work of six. Secondly, they used fluorescent tube lights with *reflectors* in all classrooms. Tube lights produce light from electricity much more efficiently than incandescent globe lights. Reflectors behind each fixture direct a significant amount of otherwise lost light energy into the study area. Finally, *Solar Shamba* has designed control boxes and wiring systems that operate with a minimal loss of electricity (see diagram next page).



Large Applications (7 or more 35W modules)

Large arrays of solar cell modules may be economical for some applications. Two thousand solar water pumps lift water for irrigation, cattle-watering and human consumption in remote sunny locations of the world. Radio relay stations are often powered by large arrays of modules. The electric needs of a hospital or remote hotel could also be met by solar cell modules. Presently, there are several power stations in the USA that use arrays of thousands of solar cell modules to produce electricity for the grid.

Solar Electric Projects in Kenya

Since 1980, the number of solar electric projects in Kenya has been increasing rapidly. Because solar electric projects are decentralised it is quite difficult to keep track of their numbers, but judging from the sale of solar cell modules, local projects are now in the thousands. Below, some common applications of solar electricity are described:

Domestic uses: Solar electric homes use solar power to run lights, radios, televisions and small appliances such as sewing machines. More than five hundred households were using solar electricity as of January 1987, particularly in Kericho, Kiambu, Murang'a, Embu and Meru. The government has installed solar cell modules to provide lighting for staff housing in Turkana. Typical solar homes use one 35 W module to meet their electric needs.

Solar lighting: More than twenty schools were using solar electric lighting for night studies as of January 1987. Systems which use from two to six solar cell modules to light classroom blocks have been installed in Meru, Embu, Machakos, Busia, Kitui, Tana River, Mandera and Taita Taveta Districts.

Health centre lighting and refrigeration: Health centres require electricity primarily for powering lights and refrigerators which keep vaccines from spoiling. Solar electricity powers more than twenty local health centres in Mandera (see photo page 22), Wajir, Marsabit, Kwale, Lamu, Kajiado, Narok and Kiambu.

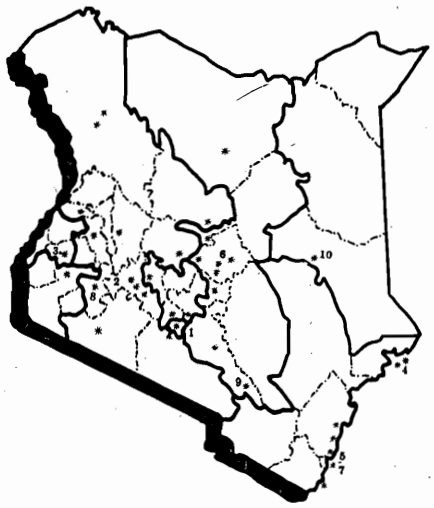
Water pumps: As of January 1987, more than 30 solar powered water pumps provided water for various applications in Turkana, Isiolo, Marsabit, Mandera, Garrisa, Kajiado, Busia, Kitui, Machakos and Kiambu Districts. About three quarters of these pumps supply water from shallow pumps for domestic needs, while most of the others supply water on cattle ranches.

Fencing: Solar electric fences prevent wild animals from destroying agricultural crops on the edges of Mt. Elgon National Park, Tsavo National Park and the Rhino Sanctuary in Lake Nakuru National Park. Solar fences also prevent livestock from straying off property boundaries on local cattle ranches.

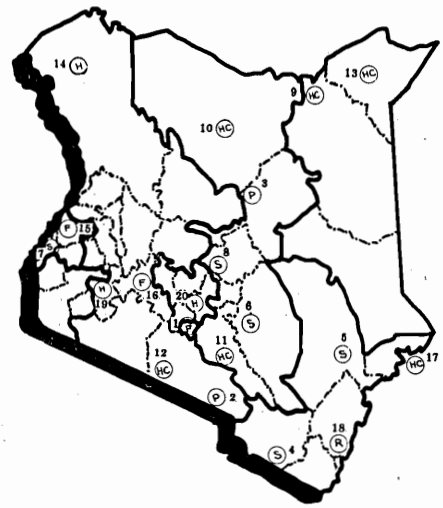
Communication: Hundreds of solar cell modules power communications devices in remote parts of Kenya. Mwangea Hill Repeater Station in Kilifi District is powered by an array of solar modules. Radios in game parks and police stations far from the grid are also powered by solar electricity.

The author (left) examines a tracking solar mount which charges six batteries supplying electricity for this school near Chuka, Meru.

Solar Water Heaters



Solar Electric Projects



Legend

P — Pumps
HC — Health Centre
S — School lighting
F — Electric fences
H — Domestic lighting
R — Radio relay station

Examples

1. Buru Buru Phase 5, Nairobi — Domestic Water Heating
2. Egerton University, Njoro — Domestic Water Heating
3. Golf Hotel, Kakamega — Tourism
4. Peponi Hotel, Lamu — Tourism
5. Mombasa Beach Hotel — Tourism
6. Nkubu Hospital, Meru — Hospital
7. Mariakani Veterinary Centre, Mombasa — Hospital
8. Tenwick Hospital, Bomet — Hospital
9. Honey Refinery, Kibwezi — Rural Industry
10. Leather Processing, Garissa Rural Industry

Examples

1. Pump, water supply — Kahawa
2. Pump, livestock — Ngatatek
3. Pump, community water supply — Laisamis
4. School lighting — Kitumbi Sec. Sch.
5. School lighting — Hola Sec. Sch.
6. School lighting — Kauma Sec. Sch.
7. School lighting — Namboboto Sec. Sch.
8. School lighting — Karamugi Sec. Sch.
9. Health Centre lighting — Bute
10. Health Centre refrigerator — Marsabet Catholic Mission
11. Health Centre — Kibwezi
12. Health Centre refrigerator — Olkira mation
13. Health Centre refrigerator — Takaba
14. Government housing lights — Kakuma
15. Electric fencing — Mt. Elgon
16. Electric fencing — Nakuru rhino reserve
17. Health Centre — Lamu
18. Mwangia Hill Radio Repeater Station
19. Domestic electricity — Over 50 homes in Kericho
20. Domestic electricity — Over 50 homes in Kiambu and Murang'a

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Hydropower 6

Power in Moving Water

Hydropower is the energy contained in moving water as it descends towards sea level. This energy can be traced to the *hydrological cycle* powered by the sun, which causes water to evaporate from lakes and oceans, carries it as clouds over land masses and deposits it as rain.

The pulling force of *gravity* gives water above sea level *potential energy*. As water rushes downhill toward sea level, this potential energy is converted to *kinetic energy*. The tremendous power of moving water pushes against anything in its path, displacing heavy boulders and tree trunks and, over the course of centuries, carving valleys between mountains. This power can be harnessed to do useful work.

Moving water in rivers and streams is diverted and put to such use as turning the shafts of grinding stones or generators. Waterwheels, turbines and hydraulic rams extract energy from moving water. These machines are efficient, long-lasting, clean-running and often the cheapest source of power for a site. The kinetic energy in falling water is much easier to convert to rotating mechanical power than heat or steam energy produced by diesel or geothermal power sources.

Hydropower now plays an important role in Kenya, supplying most of the country's industrial and domestic electricity. Large turbines such as those installed in the Tana and Athi River Basin have only partially exploited the country's hydropower potential, and new hydropower projects are now being developed.

Kenya also has potential to develop hydropower on a very small scale. Some individuals in remote areas have installed *microhydro turbines* (turbines generating 100 kW or less, see table 6.1) to provide their own electric needs. Many communities could use hydropower from waterwheels or hydraulic rams to provide mechanical power for milling or pumping water.

This chapter discusses how large and small-scale (i.e. micro & mini) hydropower has been applied to meet development needs, the potential for hydropower in Kenya and the steps one must take in order to decide whether to install hydropower. Some popular types of hydroelectric turbines which supply electricity are also described.

Table 6.1: Hydropower Installation Categories

Large	1001 kw(1 MW)	or more
Small	501 -	1000 kw
Mini	101 -	500 kw
Micro	100 kw	or less

Source: Local Experience with Micro-hydro Technology, SKAT.

History of Hydropower

The first hydropower machines were simple waterwheels developed about two thousand years ago. Antipater of Thessalonica (an ancient Greek wiseman), amused after seeing one of the first waterwheels, wrote that the servant girls would no longer have to wake at dawn to grind maize because "water nymphs" could thenceforth do the work. Indeed, these "water nymphs" were doing heavy work in developing societies; grinding and milling in the Middle East and Europe, and blowing air into iron furnaces in China.

The waterwheel, like the windmill, was spread and improved upon as people migrated to different countries and adapted new skills and technologies. Historically, the waterwheel played a key role in industrial development. Mechanical principles first demonstrated by waterwheels led to the development of the turbine, steam engine and internal combustion engine. As early as 1760, Englishman J. Smeaton had developed a waterwheel which converted kinetic energy in water to rotating mechanical energy with 70% efficiency. A little over 100 years later, there were 23,000 waterwheels operating in the eastern parts of the United States (9,700 in New York State alone). These rural watermills powered small factories which produced such goods as flour, furniture, brushes, knives, clocks, fertiliser, agricultural tools, barrels, wheels and clothes.

During the second half of the 19th century, inventors were refining *turbines* much smaller in size than waterwheels which could produce more power per head and flow of water. Between 1880 and 1925 turbines such as the Pelton wheel, the Francis, the Kaplan and the "cross flow" were invented. Turbines had replaced waterwheels in many sites by 1900, both powering mechanical equipment and generating electricity for lighting. As demonstrated by Switzerland, which had almost 7,000 turbines and waterwheels operating in 1914, small turbines were important sources of power through the 1930s. However, with the advent of rural electrification and cheap petroleum-powered generators, micro-hydropower declined in popularity in developed countries. Nevertheless, hundreds of important hydroelectric projects have been built worldwide for electrical power supply since 1925.

China, more recently, has exploited its hydropower potential by building micro, mini, small and large hydropower installations *at the same time*. The government has planned hydropower stations so that diversion dams and canals serve several purposes: *controlling flooding, irrigating crops* and *generating electricity*. In 1949 there were only 50 hydroelectric power stations (producing 56 MW) in the entire country. But, during the 1950s and 60s the Chinese government intensively trained people to build and manufacture small hydroelectric turbines locally. By 1960, there were 4500 small, mini and micro hydropower stations producing about 200 MW of power for the country. Fifteen years later, there were 60,000 micro and mini hydro plants in China, producing 2000 MW. The number had risen to almost 90,000 installations by 1980 and this power has helped China become an important manufacturing country.

Hydropower in Kenya

Although Kenya's hydropower potential is far less than the potential in China or the United States, its significance grows as the country develops. Of the 559 total megawatt capacity generated for Kenya's grid (in 1987) more than 353 MW is supplied by hydroelectricity. By 1991, when Turkwel and Kiambere hydropower stations come into line, hydroelectric power plants will have a total installed capacity of over 600 MW in Kenya. Kenya's important water catchment areas fall under the supervision of 3 development authorities: The Tana and Athi River Development Authority (TARDA), The Lake Basin Development Authority (LBDA), The Kerio Valley Development Authority (KVDA).

Another river basin, the Ewaso Ngiro, flows northward from Mt. Kenya into the semi-arid land where it evaporates or is lost in the soil. So far, no major attempts have been made to make use of the hydropower potential in the basin.

Projects have been completed (or are being completed) in each of the other three catchment areas. The TARDA is the most highly developed basin with several dams which exploit a great portion of the river's potential. Table 6.2 describes the major hydroelectric stations in Kenya, their installed capacity, gross head, type of turbine and year of installation.

Table 6.3 describes the estimated hydropower potential in the various basins in Kenya. It is based on incomplete hydrology data, and thus all sites will require complete economic study before hydroelectric plants can be built. The gross capacity in MW of a river is always higher than the hydroelectric potential that can be economically installed.

Table 6.2: Existing and Committed Hydro Plants in Kenya (1987)

POWER STATION	RIVER	GROSS CAPACITY (MW)	NUMBER OF UNITS	GROSS HEAD (M)	AVERAGE FLOW (M^3/SEC)	LIVE STORAGE (MCM)	TYPE OF TURBINE	YEAR INSTALLED
Mesco	Maragua	0.4	1	-	-	RR*	Francis	1933
Ndula	Thika	2.0	2	32	-	RR*	Francis	1925
Sagana	Tana	1.5	3	37	-	RR*	Francis	1955
Gogo	Kuja	2.2	2	25	-	RR*	Kaplan	1958
Selby	Sosiani	0.4	2	40	-	RR*	Pelton	1952
Wanjii	Maragua	7.4	4	115	-	RR*	Francis	1952
Tana	Tana	8.0	2	54	15.5	RR*	Francis	1954
	Maragua	6.4	3	70	69.1	RR*	Francis	1933
Masinga	Tana	40.0	2	50	91.9	1410	Kaplan	1981
Kamburu	Tana	94.2	3	82	91.9	135	Francis	1974
Gitaru	Tana	145.0	2	144	91.9	13	Francis	1978
Kindaruma	Tana	44.0	2	37	91.9	8	Kaplan	1968
Kiambere†	Tana	144.0	2	145	91.9	485	Francis	1988
Turkwel†	Turkwel	106.0	2	370	19.3	614	Francis	1991
Total		**601.5**	**33**					

* Run of the River (see Dams section)
† Under construction (1987)

Source: Kenya Power and Lighting Co,1987.

Table 6.3: Estimated Undeveloped Hydropower Potential

BASIN	GROSS CAPACITY(MW)	AVERAGE ENERGY (GIGAWATT-HOURS)
Lake Victoria Drainage Basin		
Nzoia	60	306
Yala	60	305
Sondu	120	568
Kuja	18	89
Sub-total	**258**	**1268**
Rift Valley Area		
Kerio	40	170
Ewaso Ngiro	118	304
Sub-total	**158**	**474**
Athi River Basin		
Athi	84	465
Tana River Basin		
Tana	472	2100
Ewaso Ngiro North Basin		
Ewaso Ngiro	155	675
Total Potential	**1127**	**4982**

Note: The hydro potential estimates are preliminary and may change by as much as 40% when feasibility studies are undertaken.

Source: KP&L Co., 1987.

Small-Scale Hydropower

Small-scale hydropower devices include waterwheels, microhydroelectric installations, turbine pumps and hydraulic rams. As was the case with windmills, small-scale hydropower devices were brought to Kenya by European settlers, who made extensive use of them in Kericho, along the slopes of the Aberdares and Mt. Kenya and in Western Kenya. However, after independence small-scale hydropower devices fell into disuse because there were few people qualified to repair them and because the government was concentrating its efforts on *grid electricity* programmes. Nevertheless, small-scale hydropower projects are still working in parts of the country with high rainfall. Microhydroelectric plants installed before independence still produce power for several farms in Kenya. Waterwheels are also still in use in a surprising number of sites, grinding maize, running lathes and even generating electricity.

Many Kenyans are solving their water supply problems with small-scale hydropower. It is estimated that there are over 2000 *hydraulic rams* pumping water around the country and at least three local companies make good quality hydraulic rams. One company has started production of a waterwheel for pumping water as well.

Although there are few microhydroelectric installations in Kenya, it does not mean there is no potential. The most economical sites are those more than 25 km from the grid near streams with a reasonable energy potential (one study estimated that there are more than 100 such sites in Kenya). However, for small microhydroelectric units which would produce less than 10 kilowatts there are many more potential sites.

Experiences in China, Switzerland, the United States and, most recently, Nepal demonstrate that small-scale hydropower technologies are an aid to development. Hydro projects such as waterwheels, cross-flow turbines, and hydraulic rams benefited rural areas in the above countries by making power sources available and by creating employment. Kenya has a number of areas in which small-scale hydropower technologies could meet basic community needs such as pumping water, milling and generating electricity. The sections that follow describe some of the available hydropower technologies and how to apply them.

Deciding Whether to Use Hydropower

Hydropower is only economical if there is a demand for the energy. Furthermore, this demand should be as near to the power source as possible because of the high costs of transmission. Questions helpful in deciding whether to use hydropower include the following:

- How much power is needed? In what form? (see chapter 1 and 8).
- How much water power is available? Is the source dependable?
- Does the stream dry up during the dry season?
- Is hydropower the best source of power for the need? Compare hydropower to other solutions. Which is cheapest?

Some of the arguments *in favour* of small-scale hydropower include:

Power is available as long as there is a flow of water. Clouds may block solar energy, the wind may stop blowing, and the price of petroleum may rise, but

permanent streams flow continously.

There are a wide variety of small-scale hydropower machines. Hydropower machines differ according to the type of power needed, the rate of flow, and the available head of the stream.

Site requirements are not complicated. If there is a permanent source of falling water, there is usually some way to harness its power.

Small-scale hydropower is often economical. Well-made devices have a long lifetime and require little maintenance. The transmission and control equipment required are usually minimal and, once installation is complete, the operational expenses are low.

Two important arguments *against* small-scale hydropower should also be considered:

Suitable sites in Kenya are not widespread. Kenya's hydropower potential is located mostly in the Central Highlands and in Western Province. Other semi-arid parts of the country do not have the permanent streams needed for hydropower production. Many areas which could use microhydro electricity are near enough to the grid to make it more economical to buy grid electricity than to build microhydro power stations.

Water must be diverted to hydropower machines. All hydropower installations require that water be conveyed to them from streams or rivers. This is usually done using a dam to divert all or part of the water into a canal, penstock, or flume. Dams, canals, pipes and flumes (called *civil works*) require expensive material and construction work. Over 50% of the cost of most hydro projects is spent building water diversion structures. The smaller the hydropower installation, the cheaper the civil works.

The Power Available:
Measuring Head and Rate of Flow

Power contained in a stream of water is determined by:

1. The *head, H,* of water. This is the vertical distance (in metres) that the water falls, and,
2. The *rate of flow, Q,* of the stream. This is the amount of water flowing through the stream over a given time (measured in litres per second or cubic metres per second).

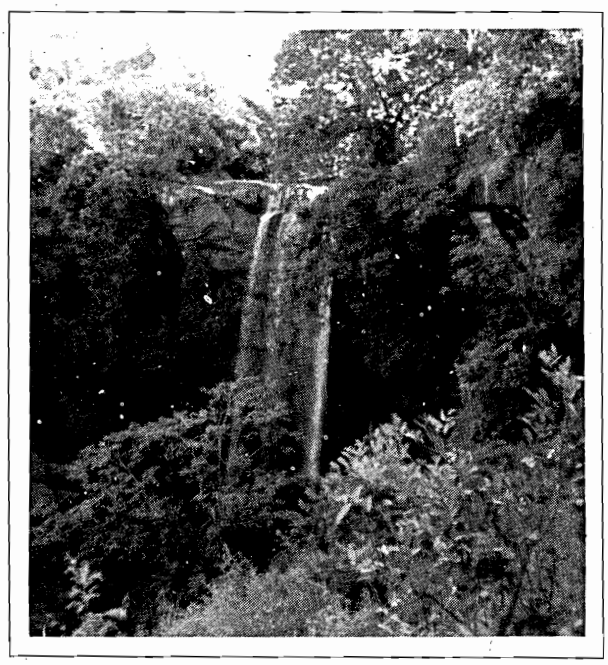
The ***theoretical power, P_t,*** (in watts) available from a stream of water is calculated using the following equation:

$$P_t = \frac{Q \times H_{net}}{102}$$

P_t = Theoretical power in watts

Q = Rate of flow of the stream in litres per second

H_{net} = Net head, or the *total head* minus losses due to friction in pipes (see page 116).



High head waterfalls like this one in Meru district have a good potential for microhydro power production.

The figure 102 is a constant derived by dividing the number of litres of water per cubic metre by the gravitational constant, 9.8 m/s^2.

The *actual usable* power, *P*, available from a stream is calculated by multiplying the theoretical power, P_t (derived above), by the percent efficiency of the hydropower machine.

Because of mechanical and transmission losses, the total theoretical power in the moving water cannot be collected by the hydropower machine. The actual energy collected is usually between one third and three quarters of the theoretical power depending on the type of machine. Most hydropower machines are between 33 and 75% efficient.

The power available in a stream of moving water should be calculated when considering hydropower, meaning that both the rate of flow and the head must be carefully measured. The calculated available power will help determine which type of turbine, waterwheel or hydraulic ram is most appropriate.

Measuring Rate of Flow

Because the flow of a stream changes from season to season, it should be measured regularly over a period of time in order to get an idea of its power variations. Three measurements, in particular, should be given careful attention:

Lowest Seasonal Flow. This is the minimum rate of flow experienced during the last months of the dry season. The lowest flow is used to calculate the *firm power*, the minimum guaranteed power, that a hydroelectric plant will produce.

Average Monthly Flow. Daily rate of flow measurements taken over the thirty days of a month are averaged together to get the average flow per month.

The data gives a good idea of how much power an installation will produce per month, and when compiled, the total energy that can be expected to be produced in a year.

Highest Seasonal Flow. This is the maximum rate of flow, which occurs during the months of the rains. Knowledge of the maximum rate of flow helps in planning against damage to a hydropower installation during floods. Knowing the *high level* that the water will reach is often more important than knowing the actual flow volume.

Measuring Small Streams

Flow in small streams can be easily measured by diverting all of the water into a large container of known volume. Dividing the total amount of water diverted by the time used to fill the container will give the flow rate (Q).

Example:

A bucket with a volume of 16 litres is filled by the diverted flow in 20 seconds.

$$Q = \frac{\text{Volume of water container in litres}}{\text{Time to fill container in seconds}} = \frac{16l}{20s}$$

$$= 0.8 \text{ litres per second}$$

Measuring with a Weir

This method measures the amount of water passing through a notch in a small dam called a *weir*. The weir, made from boards or logs, is constructed so that all the water in the stream flows through a rectangular-shaped notch in its centre (see figure). A stake is driven into the stream bed upstream from the weir (about 2 m) so that its top is level with the edge of the notch opening. The height of water above the stake is then measured and a fairly accurate flow reading can be obtained using a standard *weir table* (see Table 6.4) to correlate the height of water above the stake and the width of the notch.

Example:

A weir with a notch opening of 1 metre (100 cm) is built. The height of water above the stake is measured as 25 cm. Using table 6.4, a rate of flow of about 220 litres per second is estimated.

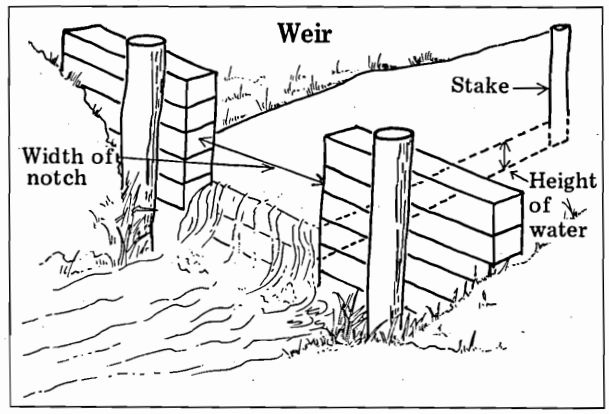


Table 6.4: Flow Rate per 10 cm Width of Weir

DEPTH (H) (in cm)	FLOW (liters/sec)	DEPTH (in cm)	FLOW (litres/sec)
1	0.2	15	10.4
2	0.5	16	11.4
3	1.0	17	12.4
4	1.4	18	13.5
5	2.0	19	14.7
6	2.7	20	15.8
7	3.4	21	17.0
8	4.1	22	18.1
9	4.9	23	19.4
10	5.7	24	20.6
11	6.6	*25*	*21.9*
12	7.5	26	23.1
13	8.4	27	24.4
14	9.4	28	25.7

The Float Method

This is a very rough but quick method used to calculate the flow of streams in which a weir cannot be built. First the speed of a float (i.e. a bottle or log) is measured in metres per second along a straight section of the river. Next, the approximate cross section area of the stream is estimated (in square metres). Multiply the speed of the float (m/s) by the cross section area of the stream to get the approximate rate of flow in cubic metres per second.

Example:

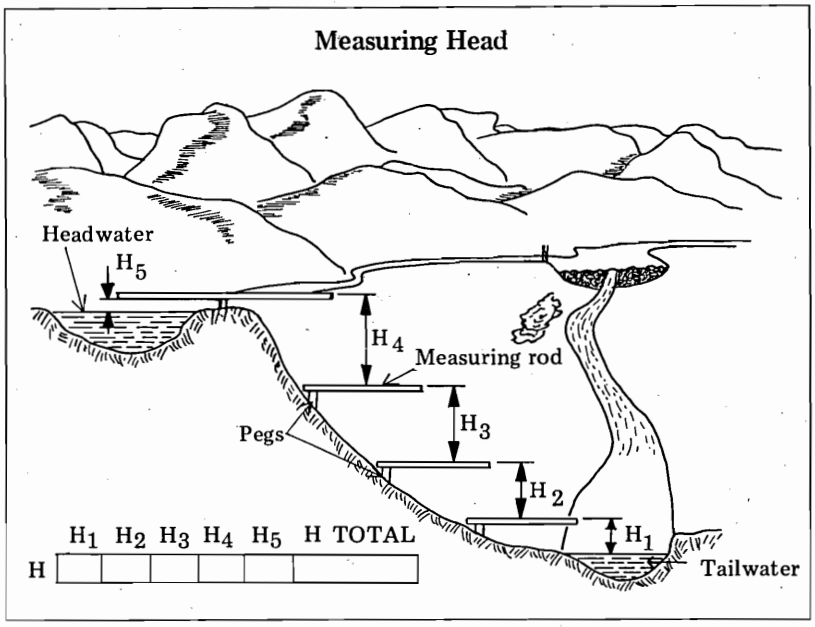
A log floats down a straight one hundred metre section of a large stream in 50 seconds, thus travelling at a speed of two metres per second. The cross sectional

area of the stream is estimated to be 2.5 square metres. The speed of the float, 2 metres per second, times the cross sectional area, 2.5 square metres gives a rate of flow (*Q*) *product* of 5 cubic metres per second.

The more accurately the rate of flow is measured, the more predictable the power output of any hydro installation will be.

Measuring Head

The *total head (H)* is the vertical distance from the surface of the water above the potential intake to the hydropower device (called the *headwater*) to the point where the water would leave the turbine or waterwheel (called *tailwater*).



Two people can measure the *head* at most small-scale hydropower sites using some pegs, a spirit level and a measuring rod, as explained below.

1. Drive pegs into the ground in intervals of the length of the measuring rod used (i.e. 3 metres) in a straight line, according to the planned course of the penstock, flume or drive pipe. All pegs should stand out of the ground at an equal height.
2. Put the measuring rod atop the first peg and keep it horizontal with the help of a spirit level. Now measure the vertical distance from the next peg to the measuring rod. Enter positive or negative values found into the table as shown (H_1, H_2, H_3 ...).
3. The total head, H , is equal to the sum of all positive values H minus the sum of all negative values.

The *net head* (H_{net}) is always less than the total head (H). This is because whenever water is conveyed through a pipe or a *penstock* (pipes or ducts which carry water into a turbine) some of the head pressure is lost due to friction in the pipe. Pressure is also lost due to bends in the penstock. The net head is thus the actual head of pressure available to drive the turbine, waterwheel or hydraulic ram after pressure losses have been deducted.

Choosing a Site

Maximum power will be economically produced at a site under the following optimum conditions:

- **Greatest head possible.** Higher heads lower the cost of the hydropower machine.

- **As short a distance** as possible between the water source and the hydropower installation. This reduces civil works costs.

Economical small-scale hydropower sites should meet several other standards. First, the power generating plant should be close enough to the place where the power will be used to avoid expensive power transmission costs (or, in the case of hydraulic rams, to avoid long, expensive runs of pipe). Secondly, the site location must be in a place where the costs of water diversion are not too high. Large dams and long canals, penstocks or flumes are expensive.

Parts of a Hydropower Installation

Civil Works

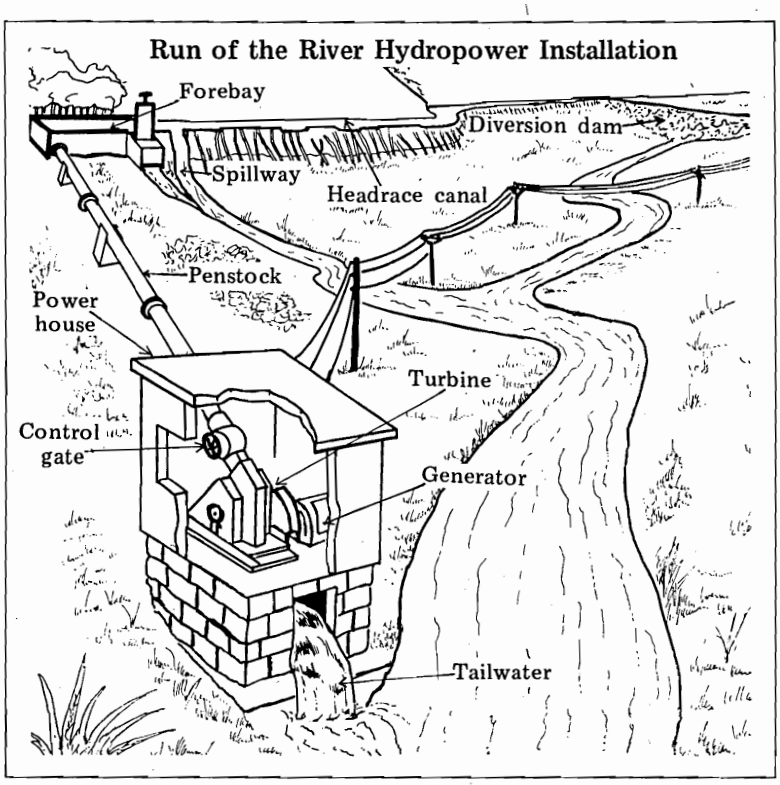
In any hydropower installation, water must be diverted from the stream to the hydropower device. Generally speaking, there are two ways of doing this. The first way, called a *regulated* system, completely dams the river or stream and feeds the water to the hydropower device via a penstock. Excess water is allowed to escape over the top of the dam via a *spillway*. Building a dam across large streams or rivers requires major *civil works*, construction jobs which store and or divert the water.

A second method called *run of the river*, diverts *part* of the stream with a small dam or weir, conveying that water to the hydropower machine by flumes, canals and/or penstocks. This type of diversion is often the best choice for small-scale hydro installations.

Dams

Dams fulfill several useful functions. First, by storing water behind them, they ensure a regular flow of water to the turbine or waterwheel even during times when the flow of the stream is low. Stored water in a dam is stored potential energy. The huge Masinga Dam stores enough water to ensure that all of the power plants below it on the Tana River have a constant flow of water during the dry season. Stored water behind a dam can also be used for fish farming, irrigation and recreational purposes.

Secondly, dams raise the *head* of a stream, thereby increasing the easily obtainable power. In a



small stream, the head can be raised several metres by choosing an appropriate site for building the dam.

Thirdly, dams enable easy diversion of water to the turbine or waterwheel. In a run of the river installation, a partial dam simply diverts some of the flow into a canal (called the *head race*) or flume which carries it to the hydropower device. In a regulated installation, the water flow is completely blocked and fed directly into the hydropower machine located below the dam.

Depending on the size of the hydropower installation, dams are built of concrete, stone, wood or even earth. Run of the river diversion dams are usually much simpler to built than the full dams required in regulated installations. Because a dam burst will cause considerable damage downstream, structures called *spillways* which allow excess flood water to escape must always be part of the dam design. The smaller the dam, the safer it is and the easier and cheaper it is to build. All dams should be built by qualified experienced individuals.

Dams permanently change the flow of rivers and streams. They cause the water table to be raised upstream and lowered downstream. Agricultural land may be flooded by water behind the dam. Meanwhile, the altered flow of water will effect the downstream inhabitants and ecosystems. Furthermore, dams can act as breeding grounds for such disease organisms as malaria and bilharzia. For these reasons, and because of the special problems of dam building, any project that will affect the flow of a stream or river in Kenya requires consultation with the Ministry of Water Development beforehand.

Flumes, Headrace Canals and Penstocks

Every hydropower installation requires some means of conveying water from the dammed stream to the turbine, waterwheel or hydraulic ram. The water should be conveyed with as little *head loss* and *expense* as possible from the dam.

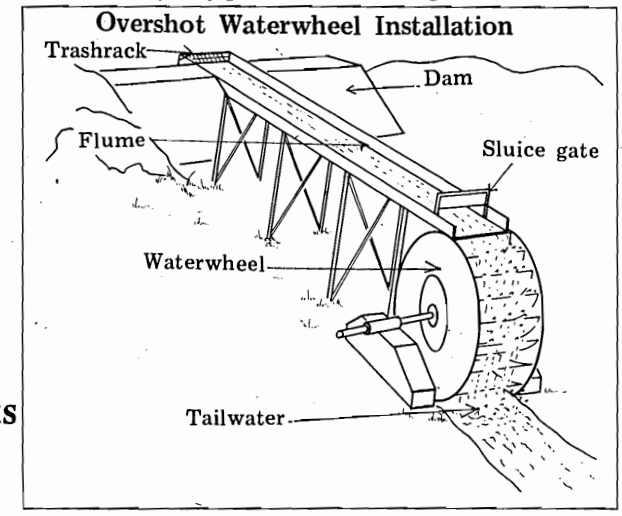
Headrace canals and *flumes* are open channels built with a very slight gradient so that little energy is lost from the water as it travels through them. Headrace canals are built along the contours of the land in such a way that erosion is minimised. Flumes (or *sluices*) are water channels made from wood, metal and concrete that carry water over obstacles or narrow valleys. Overshot waterwheels always require flumes to supply them with water.

Headrace canals and flumes used in run of the river hydroelectric installations empty into concrete or stone boxes called *forebays*. The forebay guides the flow of water into the penstock which carries it to the turbine. The forebay also allows escape of excess water via a spillway and settling out of sediment in the water.

Penstocks are pipes used to carry water from the dam or forebay to turbines. The correct diameter and strength of penstock for the given flow of water should be chosen carefully. Penstocks for microhydro installations may be made from PVC pipes but larger sites require strong steel pipes or even concrete culverts. Long penstocks are quite expensive. Note in the diagram above that the penstock is anchored into the ground with concrete to prevent it from shifting position.

Water friction against the inside of the pipe and against bends in the penstock cause *head loss* which reduces available power. Typically, a ten percent head loss can be expected in any small-scale hydropower system. Manufacturers of turbines and hydraulic rams can help in choosing the correct pipe size for each flow to minimise these head losses. The following tips will also help minimise head loss.

- Never use old steel pipes. New steel or PVC pipes are best.
- Choose pipes of the proper diameter.
- Always lay penstocks in a straight line .



Control and Screening of Water Flow

Water flowing into a hydropower installation should be controlled to prevent damage to the hydropower device during floods and to allow occasional maintenance. Penstocks, by virtue of their diameter help limit the amount of water that flows into the turbine, but they always have *control valves* and or *gates* in the forebay which can limit water flow. Waterwheel installations have *sluice gates* (wood or metal panels which can be closed or opened) for controlling waterflow.

Water entering hydropower installations must be free from foreign matter such as leaves and sand. This is especially true with turbines and hydraulic rams which may be clogged or damaged by substances in the water. *Trashracks* (grates or screens which prevent the passage of solids) are used in turbine and waterwheel installations. Trashracks must be cleaned on a regular basis to prevent foreign matter from clogging the screens or grates.

Types of Hydropower Devices

This section discusses 3 general types of hydropower machines:

Waterwheels are large slow-spinning wheels with attached paddles or buckets which are turned by the force of moving water. They are used primarily for high torque mechanical work such as grinding.

Turbines have fast-spinning blades (called runners) that are turned by the pressure or impact forces of moving water. The most common application of turbines is electrical generation (though they can be used for mechanical work).

Hydraulic rams use the momentum of water moving through an inclined drive pipe to push part of that water uphill through a delivery pipe to a place where it is required.

Waterwheels

Waterwheels are the oldest hydropower devices, having been used in China, Persia and parts of Europe for over 1500 years. The turning wheel is typically built next to the side wall of the watermill building and the turning shaft runs machinery inside. Traditionally, watermills operated grindstones, threshers, blowers, water pumps, lathes, saw blades and, more recently, with gearing they have even been used to generate electricity. Waterwheels can be divided into two groups: *horizontal axis* and *vertical axis*. Horizontal axis waterwheels, used traditionally in Europe, include both the overshot wheel (see below) and the undershot wheel. Vertical axis waterwheels, which originated from the Middle East, are the forerunners of modern impulse turbines.

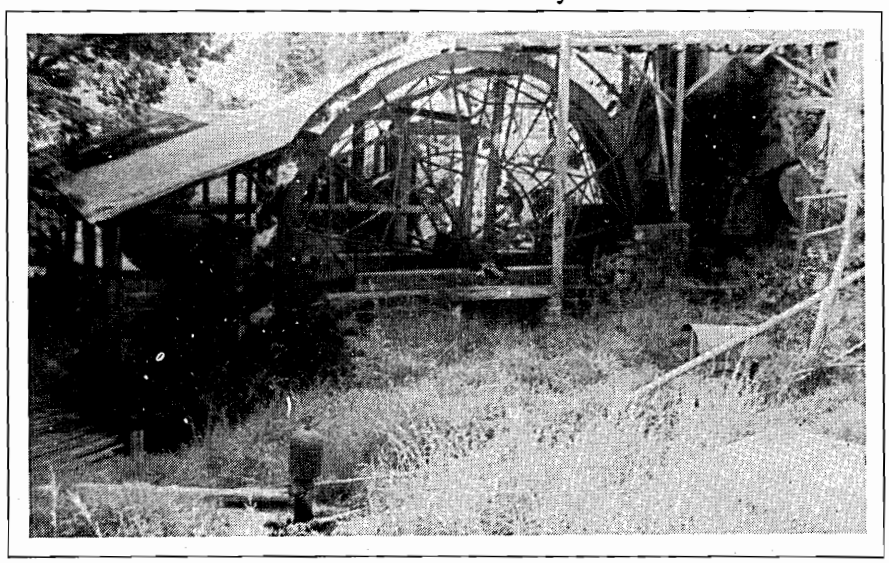
The overshot waterwheel is the most efficient and widely used waterwheel. Water moves through the flume and falls into buckets located along the rim of the wheel. The weight of the water in the buckets causes the wheel to rotate about its shaft. As the wheel rotates, water is discharged into the *tailwater* below the buckets.

On a typical overshot installation, a small dam diverts the water from a stream or canal into the flume which carries it to the wheel. The *sluice gate* regulates the water supply while the *trashrack* prevents foreign matter from entering the waterwheel. Notice that the wheel is always built so that its bottom part is above the tailwater. If the wheel is submerged in the tailwater, operation will slow down significantly. Note also that the overshot waterwheel's diameter is a bit less than the *total head.*

Pictured are two locally made and used overshot waterwheels. The one pictured below, located on the Ngare Ndare river north of Mt Kenya, has a diameter of more than 3 metres and is used to generate electricity, pump water and grind grain. It has been operating for over twenty years, requiring repair several times when the axle (from a lorry) was broken by the large torque forces. The second waterwheel (see photo page 110) was built much more recently by Ndume, a company located in Gilgil. Installed near Baraton College, Eldoret, it is used exclusively for pumping water from the stream to a household water supply.

Advantages of Waterwheels

- Simple design and construction
- Can be made cheaply with local materials
- High torque makes them suitable for mechanical work
- Can operate under large flow variations with constant efficiency



A four metre diameter waterwheel on the Ngare Ndare river, Meru, used for generating electricity, pumping water and grinding maize. Note Blake hydroram in foreground.

- Require short, simple water diversion flumes
- Simple maintenance and repair
- Can use muddy or silty water

A final important advantage of waterwheels is that they demonstrate the basic principles of water power in rural areas, promoting a technology that has immediate potential for small-scale power supply.

Disadvantages of Waterwheels

- Large size and weight, in relation to power output, make them inconvenient for some tasks.
- Slow rotation speed limits the type of energy they can produce (a gearbox increasing the rotation speed for electrical production may cost as much as the waterwheel itself).

Although waterwheels are not as efficient as turbines, their low costs mean they can deliver small amounts of mechanical power more cheaply than turbines, and hence waterwheels are often the most cost-effective power need solutions.

Example: Vertical Axis Waterwheels

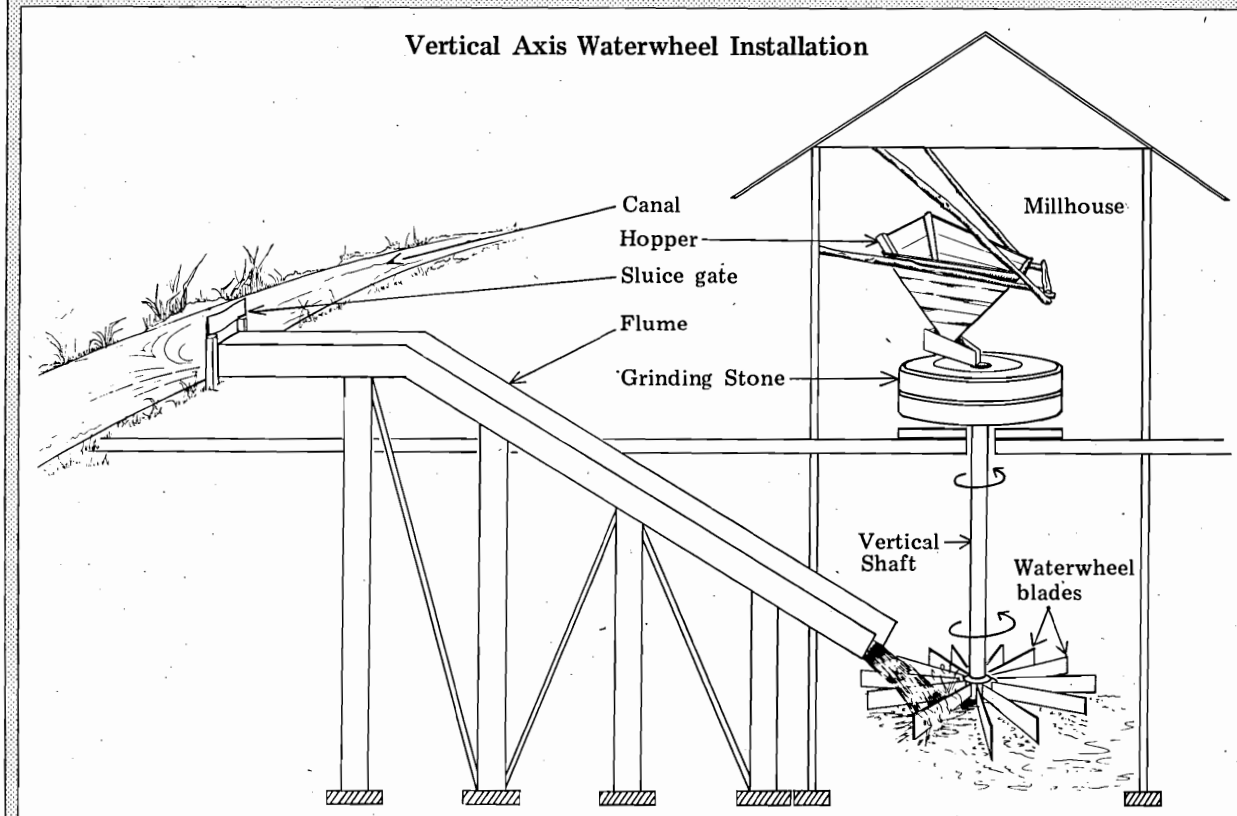
First developed hundreds of years ago in Nepal and Crete, vertical axis waterwheels are found in a surprising number of locations in Kenya. Working examples of these hydropowered maize mills are found in Kakamega, Nyeri, Kiambu and Murang'a. The wheels are made entirely from readily available materials, as even the shaft can be made from a heavy wood.

During operation, water is diverted from a canal or stream down a steeply inclined flume. As it travels down the flume, the water gains momentum and is forcefully directed onto the fan-like blades around the vertical shaft of the wheel. The fast-moving water gives up some of its energy as it strikes the blades, causing the shaft to rotate about its axis.

In the millhouse directly above, the vertical shaft is attached to a millstone. As the shaft is turned by the force of the moving water below, the millstone rotates against the stationary stone below it. Maize, fed from the hopper, is pulverised into flour between the two stones(see photo page 143).

Like other waterwheels, the vertical axis type is not as efficient as the overshot wheel. However, when the simplicity of the vertical wheel's construction and operation are considered, together with its low cost efficiency is not a major factor.

Vertical Axis Waterwheel Installation



Water Turbines

Water turbines are devices which convert the energy in falling water into rotating mechanical energy. Although the waterwheel is, strictly speaking, a type of turbine, the term now generally refers to modern devices which spin at high speeds and are used mostly for generating electricity. Water flows through passages created by the turbine *runner* , the turning shaft with attached blades or buckets, transfers its energy to the runner and then leaves the turbine with a minimum of energy and velocity.

Around 1900, there were hundreds of small turbine manufacturers in the USA and Europe, but most of these went out of business when microhydro systems were replaced by steam engines, internal combustion engines and rural electrification programmes. Large turbines have been installed in major hydroelectric dams worldwide since the 1920's. In the last ten years, mini and micro hydropower systems have increasingly been in demand by both developed and developing countries in the face of unstable petroleum prices.

Turbines can be divided into two general types:

Impulse Turbines use the velocity in jet streams of water moving through nozzles to turn fast - spinning wheels.

Reaction Turbines use the velocity of water striking runners at an angle as well as the pressure forces of water flowing across runner blades to turn the runner.

Impulse Turbines

Impulse wheels are turned by jet streams of water shooting out of a nozzle onto the buckets or blades of a spinning rotor wheel. Because they transfer a high percentage of the kinetic energy from the jet stream of water to the spinning wheel, impulse turbines are quite efficient (up to 80%). Fast spinning impulse wheels are very well suited for electrical generation.

Impulse turbines are highly developed descendants of vertical axis waterwheels and, from an operational point of view, they are the simplest turbines. Most require a high head of water, yet can operate quite well with low flows.

The Pelton wheel, patented by Lester Pelton in 1860, is the most well known impulse turbine. Water, fed through a penstock from a high head (20m and over) enters the turbine and is channelled through a nozzle under pressure. The nozzle squirts a jet of water at buckets fixed to the outer rim of the runner.

Each spoon-shaped bucket is highly polished to deflect the stream of water back on itself. By deflecting the jet of water 180°, the runner extracts a maximum amount of energy from the water. Pelton wheel nozzles squirt water on to one bucket at a time. However, by adding nozzles (up to 4), more than one stream of water can be directed at the runner, thus increasing the power output. A needle inside each nozzle controls the speed of water jet and hence the rotation speed of the wheel.

Pelton wheels are usually the best choice of waterpower for sites with very high heads. The higher the head, the smaller the turbine needed to generate a given amount of power. Pelton wheels can operate quite well in small flows.

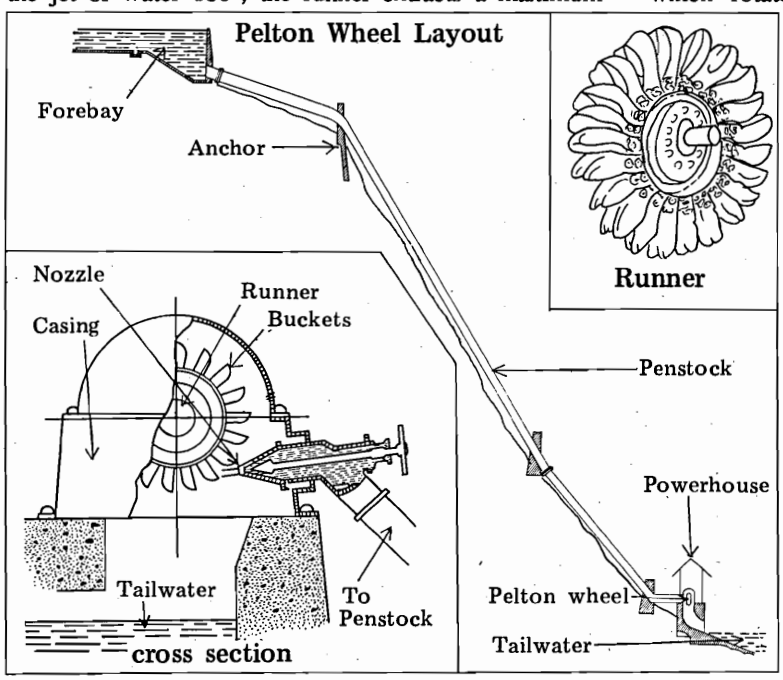
The *Turgo wheel*, an improvement of the Pelton wheel, is built so that the jet of water from the nozzle strikes *more than one bucket at a time*, thus producing more power than the Pelton wheel from the same flow and head. The Selby Falls power station on the Sosiani river generates power with two Turgo wheel units that were installed in 1952 (see figure below).

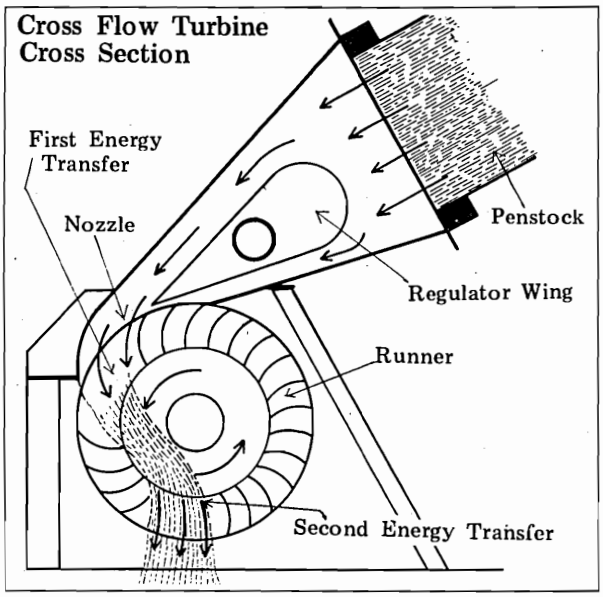
Cross Flow turbines include several similar designs (Banki, Michell) in which a stream of water passes through a drum-shaped rotor with curved blades. It is used for such tasks as electrical generation, pumping water and even milling grains. Because of their adaptability and ease of construction, cross flow turbines have been quite successful in microhydropower projects in developing countries. In Nepal, cross flow turbines are replacing traditional vertical axis waterwheels as power sources for remote flour mills. The success of cross-flow turbines has led to their introduction in eastern Zaire for food processing. There are presently between 3,000 and 4,000 cross flow turbines in operation worldwide.

Like other impulse turbines, the cross flow has two operating parts, the nozzle and the runner. Water enters the turbine through an inlet from the penstock, passes through a regulator wing that controls water flow (and thus power output), and then squirts through a rectangular shaped nozzle onto the blades of the runner which rotates on a horizontal shaft. For optimal performance, the jet of water is directed across the length of the runner blades from an angle of 16°. (See fig. next page).

The operation of a cross flow turbine is similar to that of a waterwheel. However, *two energy transfers* take place inside the cross flow turbine. After striking and passing over the runner blades the first time, the water flows through the hollow centre of the runner and again strikes the blades, transferring energy as it leaves the turbine.

The cross flow turbine has advantages that make it a good choice for many microhydropower sites. First, it is fairly simple to construct, the drum-shaped runner being cut from stock sheet metal and standard pipes. In fact, the cross flow is one of the few turbines that do not require casting and hence can be made locally (Pelton wheels, Francis turbines and most of the others are now





imported). Secondly, it is adaptable for a wide range of heads and flows. Finally, it can be fixed to do either mechanical or electrical generating work (or *both*, as is the case with cross flows in Nepal).

Reaction Turbines

Reaction turbine runners are always *completely submerged* , and power is derived from the flow of water over the turbine blades. Unlike impulse turbines, which take power only from the *speed* of moving water, reaction turbines also make use of *hydrodynamic pressure forces* in the flowing water to produce torque on specially-designed runner blades.

Reaction turbines commonly operate at high efficiencies in low to medium heads. Because their design requires careful engineering, reaction turbines are usually specifically designed for each site by foreign manufacturers. This makes them quite expensive. Reaction turbines are generally used for *megawatt* generating operations and because they are not suited for most micro-hydro applications in Kenya (too expensive, very high tech designs), they are described only briefly below.

Francis Turbines. Most of the large power stations in Kenya use Francis turbines. Water enters the turbine from the penstock (also called *pressure tunnel*) through an inlet valve. At high pressure and velocity water flows between fixed guidevanes which give it optimum flow direction. The water then flows across the curved runner blades towards the outlet at the turbine centre. Water is discharged at low pressure and velocity into the draft tube (tailwater).

Kaplan (Propeller) Turbines, also used in large hydroelectric applications, are like large ship propellers. However, unlike propellers, the runner of these turbines takes energy from the water flowing across it. Water enters the turbines through an inlet on the side and is directed downward by guidevanes an angle that causes the runner to rotate optimally. As with the Francis turbine, water enters the turbine at high pressure and velocity and leaves at low pressure and velocity.

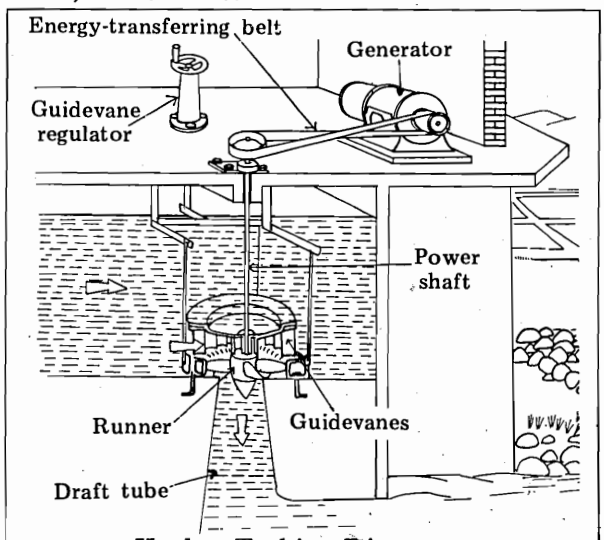
Hydraulic Rams (Hydrorams)

Hydraulic rams use a principle of physics called the *water hammer effect* to pump water from a stream or river up to a place where it is needed. First developed by a Frenchman named Montgolfier in 1796, they were originally used to pump water in the fountains of French palaces. In Kenya, the hydraulic ram is now one of the most common water pumping tools.

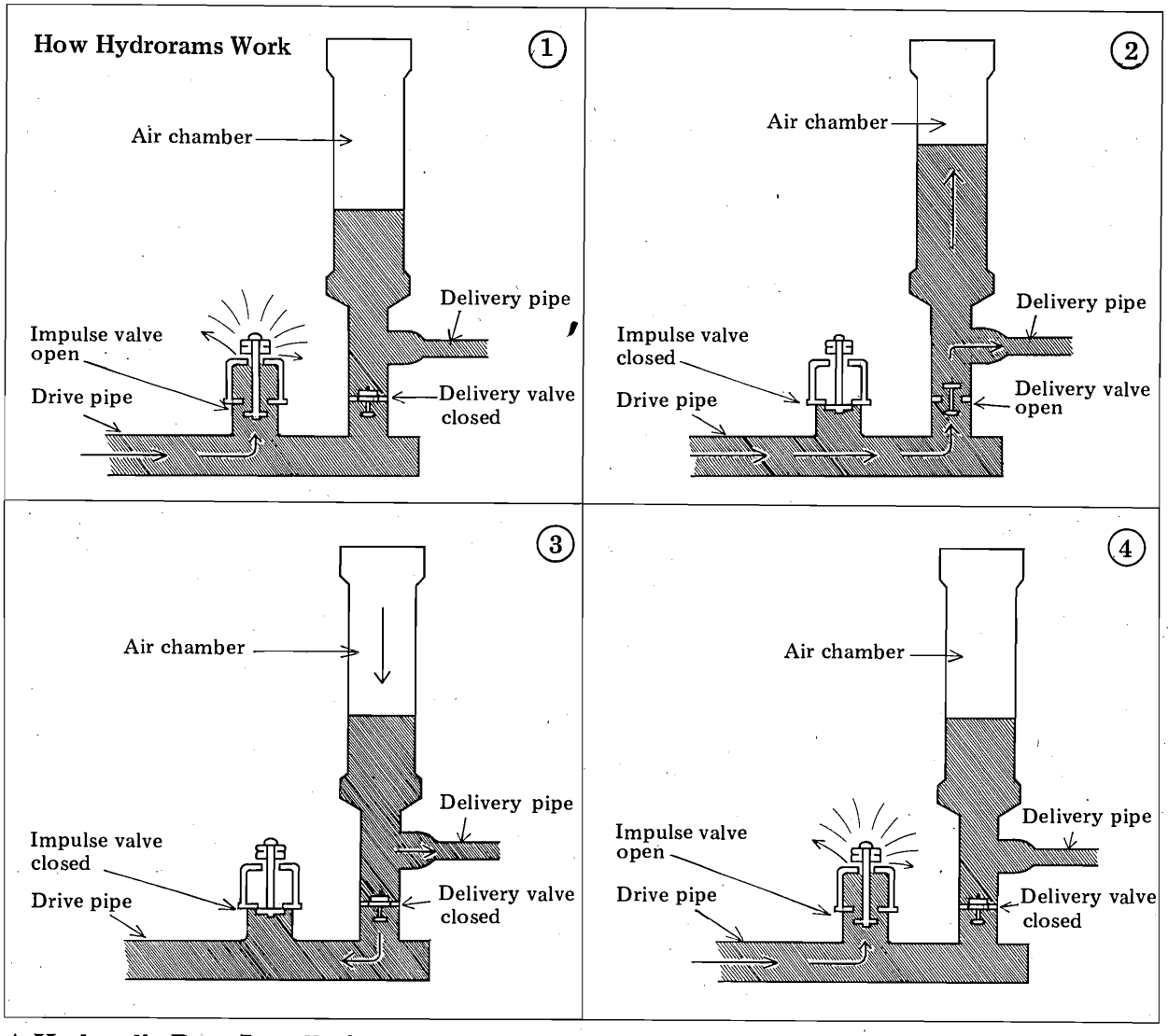
Hydrorams were popular with European settlers and many people today remember them because they supplied water for colonialist encampments during Mau-Mau. They are so reliable that, years after installation, when they finally break down, people have forgotten who installed them. Hydrorams are now found in Kericho, Meru, Embu, Nyeri, Murang'a, Narok, Kakamega, Trans Nzoia, Nandi, Taita and Bungoma districts (to name a few).

How Hydrorams Work (see diagram next page)

1. Water flows with much speed and momentum through the *drive pipe* (an inclined pipe leading from the drive tank, see layout diagram page 123) into the hydraulic ram and out through the open *impulse valve*. After a fraction of a second, the pressure of the water's momentum suddenly forces the impulse valve to close.
2. When the impulse valve closes, the moving water decelerates rapidly and this change of momentum compresses water in a high pressure "shock wave" which, by the water hammer effect, pushes open the *delivery valve*. Water rushes through the valve, momentarily compressing the air in the *air chamber* which absorbs the shock wave.
3. The air in the air chamber quickly springs back, both closing the delivery valve and forcing water up the *delivery pipe* (which conveys water to the water storage tank).
4. The impulse valve reopens as its weighted bottom is pulled down by gravity, and water again sprays out . The cycle starts again and repeats itself at regular intervals, making the characteristic "clack.., clack.., clack.." sound.



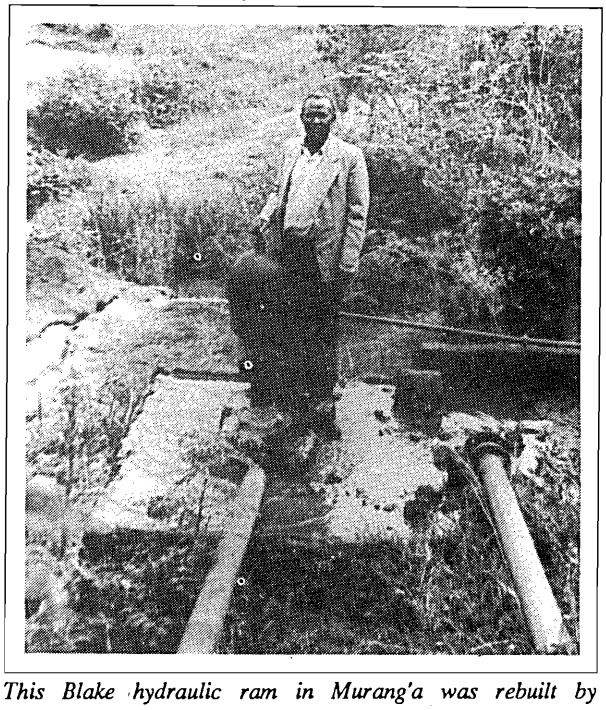
Kaplan Turbine Diagram



A Hydraulic Ram Installation

Hydroram installations require that the *drive head, delivery head* and *flow* be carefully measured at any site before building (see figure next page). The drive head is the vertical distance between the water level in the drive tank and the hydroram. The delivery head is the vertical distance between the hydroram and the storage tank (where the water is being pumped). The figure shows the parts of a typical hydroram installation, including the drive pipe, delivery pipe, water tank and ram itself. The *drive tank* (or *feed tank*) is a small dam which holds water diverted from the stream by the *feed water pipe* (which could also be a simple canal) and directs it into the drive pipe. *Screens* over the drive pipe inlet in the drive tank prevent debris from entering and clogging the hydroram.

With any hydraulic ram, most water is lost through the impulse valve at low pressure while a *much smaller volume* of water is pushed up through the delivery pipe at higher pressure. Table 6.5 (next page) shows the amount of water pumped in 24 hours up a given height depending on the head and flow of water (with a Blake hydroram). *For example*, with a three metre drive head and a 20 metre delivery head, a Blake hydroram will pump 130 litres per 24 hours for every litre per minute of flow (see table). If the flow rate is 5 litre/min flowing into the hydoram, then 650 litres (5 x 130) will be pumped into a tank 20m above the hydraulic ram each day.



This Blake hydraulic ram in Murang'a was rebuilt by Murang'a College of Technology and now pumps water to a cattle dip over a mile away.

Table 6.5: Litres Pumped in 24 Hours per Litre/Min of Drive Water (Blake Hydroram)

DRIVE HEAD	DELIVERY HEAD (METRES)									
(METRES)	7.5	10	15	20	30	40	50	60	80	100
1.0	77	65	33	29	20	13	-	-	-	-
1.5	135	97	70	54	36	19	15	-	-	-
2.0	220	156	105	79	53	33	25	20	13	-
2.5	280	200	125	100	66	41	33	24	16	12
3.0	*	260	180	*130*	87	65	51	40	27	18
3.5	*	*	215	150	100	75	60	46	32	20
4.0	*	*	255	173	115	86	69	53	36	23
5.0	*	*	310	236	155	118	94	72	50	36
6.0	*	*	*	282	185	140	112	94	65	48
7.0	*	*	*	*	216	163	130	109	82	60
8.0	*	*	*	*	*	187	149	125	94	69
9.0	*	*	*	*	*	212	168	140	105	84
10.0	*	*	*	*	*	245	187	156	117	93
14.0	*	*	*	*	*	*	265	218	167	132
20.0	*	*	*	*	*	*	*	*	237	188

*more than 300 litres

Source: *John Blake Hydrams*, leaflet

Hydraulic rams do not require extensive civil works. The *drive tank* can easily be built from stone, cement and mortar. The delivery and drive pipes, which will probably be the most expensive parts of the installation, should thus be carefully laid and anchored. Different sized hydraulic rams fit the various flows and heads of different sites and manufacturers will be able to help choose the correct size if they are given proper site information (drive and delivery head, flow rate).

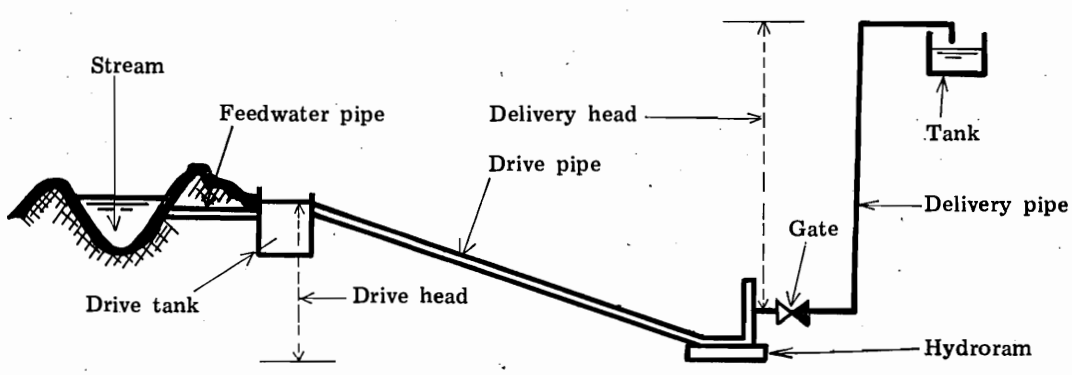
Hydrorams are commonly used to supply water for small communities, schools, domestic uses, cattle watering and small-scale irrigation. Once paid for and installed, they require no maintenance (aside from making sure that they are not buried) and will operate for many years. Even if broken, they are quite easy to repair.

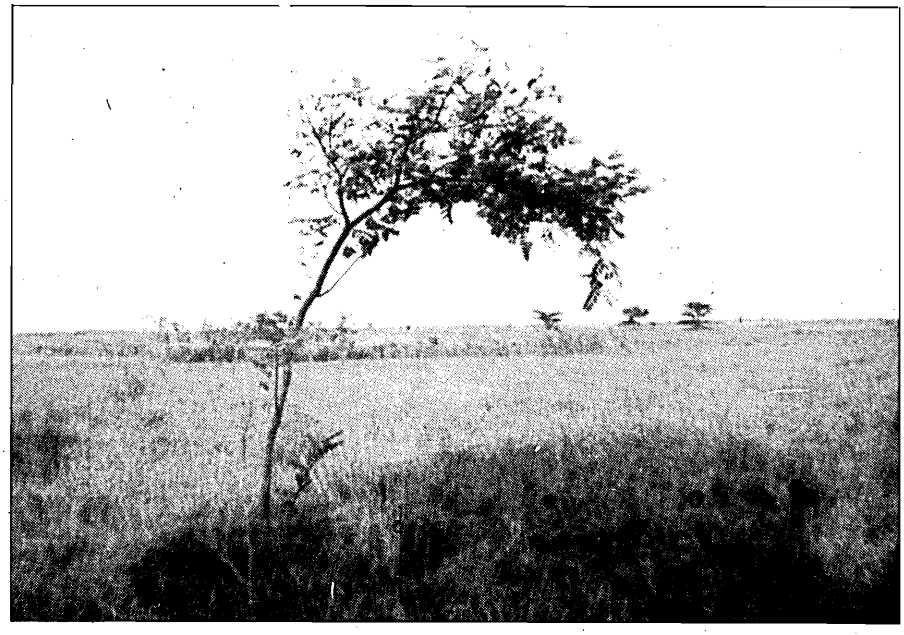
Example : The Murang'a College of Technology Hydroram

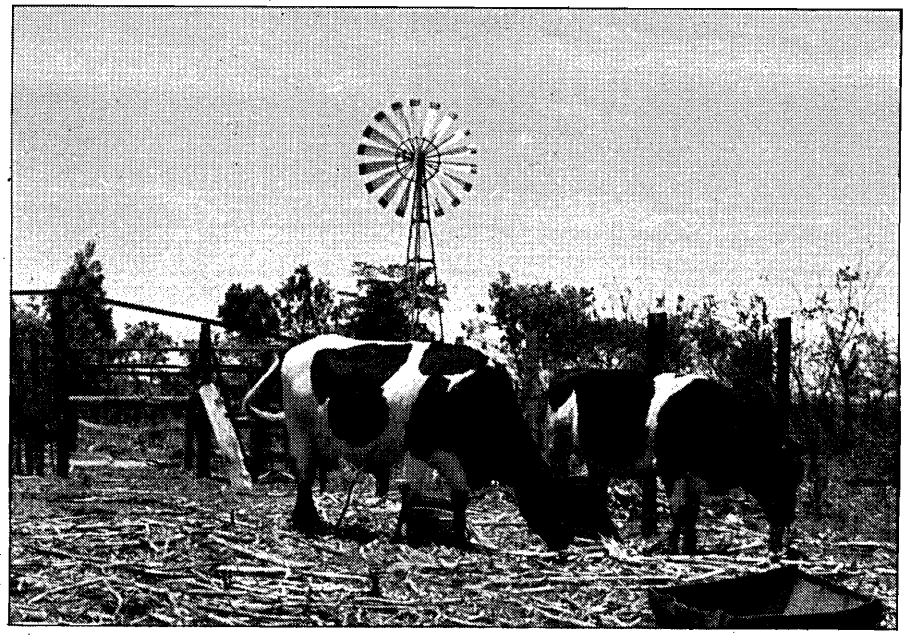
The Murang'a College of Technology (M.C.T.) hydroram was researched, developed and produced at the institute with initial assistance from the National Council of Science and Technology. Hundreds of the pumps have been installed in various parts of Kenya, especially in Kericho and Murang'a. While M.C.T.'s Mechanical Department Production Unit manufactures each unit, installation and customer services are provided by the Water Technology Department.

The pump (see photo page 23) is produced from locally available metal parts, and costs much less than imported models. It can work with a minimum drive head of two metres. The ram is made in three different sizes (2,3 &4 inches) to fit the requirements of various flow rates. The ram delivers between 3 l/min to 30 l/min up to a maximum delivery head of 75m.

MCT Hydroram Installation







Wind Energy 7

The Wind

Temperature and pressure differences in the atmosphere create moving masses of air called *winds*. As the sun heats half of the earth, the other half cools and an imbalance of atmospheric temperatures is created. Winds blow as cool air masses rush to replace warm air masses. Continents and oceans contribute to the wind activity in the conflicting ways they heat and cool the air surrounding them.

There is a tremendous amount of energy in the winds which can be harnessed to do work. *Wind machines* are devices used to convert some of this energy into usable mechanical energy for such work as pumping water, generating electricity or grinding grains. However, in order to understand wind-powered machines and how to best use them, first the characteristics of the winds must be understood.

Wind almost never blows at steady speeds for long periods of time in one location. Its speed changes from day to day, hour to hour and season to season. The direction from which the wind blows also changes.

Although wind speed and direction cannot be accurately predicted for any given moment, those who study weather have found that general wind patterns can be predicted. Wind patterns are quite regular over the years. If the weather was very windy this April and last April, it is likely to be windy next April as well.

Wind Behaviour

Wind follows general patterns on a *global, regional, seasonal* and *daily* basis:

Global Wind Patterns

There are belts between certain latitudes in which the wind intensity and prevailing wind direction are fairly constant. Around the equator, for example, there is less wind in general than in the latitudes far to the north or south.

Global wind distribution patterns are caused by a variety of factors. Atmospheric temperature and pressure differences are created by the unequal heating of the earth's surface. Meanwhile, the spinning action of the globe moves cooling and heating air masses in the direction of the earth's spin. Furthermore, much more solar energy is absorbed at the equator than the poles and this air rises and moves northward and southward. Cooler, heavier air returns to replace this air from the poles creating additional global wind patterns.

Regional Wind Factors

Regional wind patterns are caused by various geographical features. Meetings between warm and cool masses of air result in much wind activity. Extreme instances are violent cyclones, tornadoes and hurricanes. Air masses above the land heat up and cool down more quickly than air masses above the ocean. Consequently, air masses above land and sea are at different temperatures, and when they come in contact along shore areas storm activity often results.

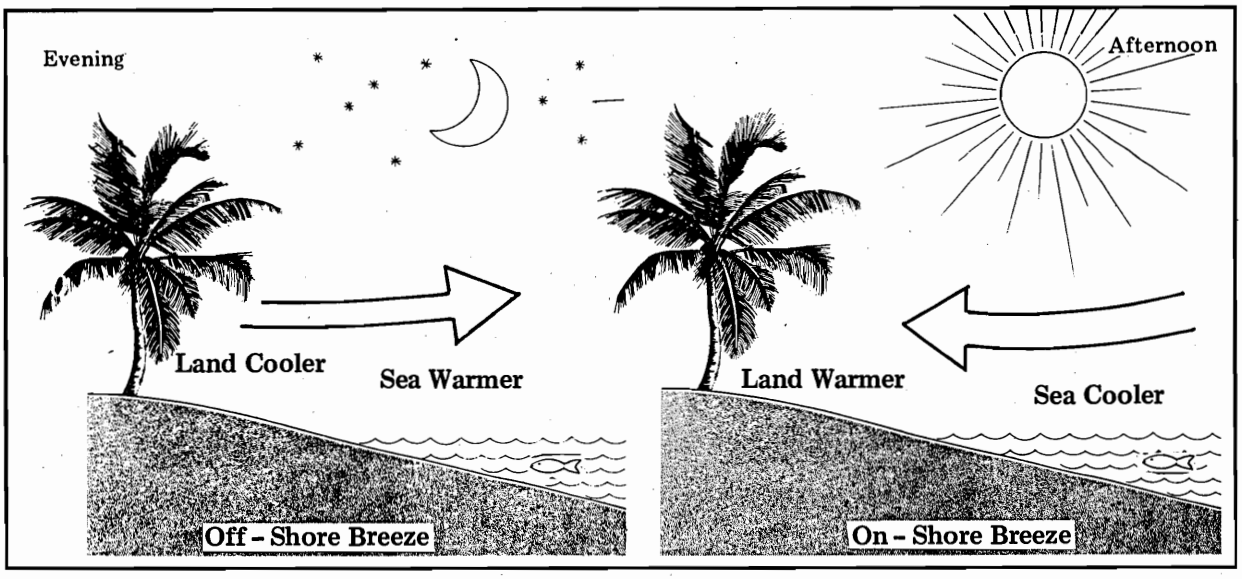
Ocean and lake breezes are regional winds that are regular and useful. Land radiates heat to the air above it in the afternoon. This air rises and is replaced by cool air from the ocean. Called *on-shore breezes*, these winds are often strong enough to power wind machines (as in Malindi, Lamu, Mtwapa and Rusinga Island).

Mountainous areas also have local winds. Mountainsides heat up during the daytime and warmed air rises from their slopes. Cool winds from the valley move up the mountainside to replace this rising air. Then at night, cold air from the rapidly cooling mountain rushes downhill to replace warm air rising from the valley below. This cycle continues day and night throughout the year.

Regional topographical features such as ridges, mountains, gorges, passes, canyons, valleys and cliffs have a great effect on the prevailing wind patterns, channelling, accelerating or even blocking wind movements. Barriers (trees or buildings) also have a significant effect on regional winds.

Seasonal Wind Features

Changes in the angle of the earth to the sun cause northern and southern parts of the globe to heat unequally, and seasonal winds equalize these differences. Seasonal wind variations are especially felt in the high northern and southern latitudes where there are winters



and summers. On the Great Plains of North America, for example, wind is most available during the very cold months of January and February.

There are major seasonal wind changes at the equator as well. This is especially true at the Indian Ocean Coast which experiences high winds during the rainy monsoon months. The dry harmattan winds in the northern parts of Africa are also examples of seasonal winds.

Daily Wind Patterns

The temperature differences between day and night cause daily wind changes. These wind variations differ with each site's topography. Winds in Kenya are typically strongest during the afternoon and lightest in the late evening.

Prevailing Winds and Energy Winds

In any location, the winds can be divided into two general types:

Prevailing winds are the winds that blow most of the time in any area (70% of the time). Depending on the area, they have speeds of 2-5 metres per second (5-20 kph) and are usually considered low energy winds. Prevailing winds always blow from the same direction.

Energy winds contain much of the useful energy available to wind machines. They blow about 30% of the time at much higher speeds (4-11 m/s or 15-40 kph) than the prevailing winds. Energy winds often come as "gusts" (sudden bursts of wind) and tend to blow from a direction that is 15-70 degrees off the direction from which the prevailing winds blow.

Winds in Kenya

Kenya's winds are influenced by the equatorial northeast and southeast monsoons. The monsoons affect surface wind speeds and direction. However, the general *wind regime* (pattern of wind behaviour) is low in energy like most wind regimes near the equator.

The useful wind in Kenya results from either thermodynamically governed conditions or local geographical features. Thermodynamically induced winds result from uneven solar heating and cooling of land and water masses. They cause the regular winds that blow on the shores of the Indian Ocean and Lake Victoria, and the winds that blow in and out of desert regions to the north of Kenya. Local geographical features cause the wind to change speed or direction as it passes over and around them. These features include the Rift Valley, Mount Kenya and various canyons, hills and gorges across the country.

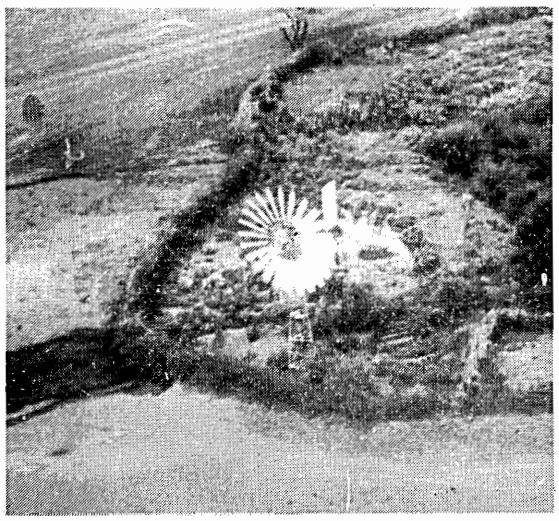
Because of Kenya's large size and the limited amount of wind information available, it is difficult to generalise about winds in Kenya. Many localities have constant steady winds. In fact, there may be regular winds in one place and almost no useful winds in a place a few kilometres away. For this reason, it is important that every wind site be *completely evaluated* before a wind machine is installed.

There are three general areas in Kenya where wind performance has been studied and confirmed. These areas are where most of the country's operating windmills are found. The following sections describe locations with good wind potential based on a recent study of winds in Kenya (see also Table 7.1).

North Western Kenya

Meteorologists have found that there are usually strong winds along the edge of deserts. As the table indicates, Kenya's strongest winds are in the semi-arid north western sections. Meteorological stations along the Turkwel river and north of Lodwar have information which suggests high wind power resources in those regions. *Windpumps,* wind machines used to pump water, have been successfully installed in North Western Kenya to provide water for cattle, domestic uses and small-scale irrigation.

The table shows that the winds in North Western Kenya are strong *throughout* the year. As wind energy is constantly available, storage systems (water tanks for water and batteries for electricity) do not have to be very large. Available information



Aerial photo of 6.1m windpump' in Kaikor, near the Sudan border, which provides water for 4000 people.

indicates that wind conditions are also strong in parts of North Eastern Kenya. Wind machines have been successfully installed in the Marsabit and Wajir areas.

The Coast

Trading dhows have made use of offshore winds at the coast for hundreds of years and the Swahili sailors who travel between Lamu and Zanzibar are experts on Kenya's coastal winds.

Winds at the coast are quite consistent. Average annual wind speeds indicate that the coast has a good potential for wind machines. Already almost one hundred wind machines have been installed between Lamu and Mombasa.

Notice in the table that the months of November and December show lower average wind speeds. Therefore any installed wind machine would probably perform at a lower level during these months. Sufficient storage tanks or batteries would be necessary to offset these low winds.

Notice also the difference between the wind data of Magarini and Mombasa which demonstrates that even at the coast each possible site must be carefully evaluated.

Lake Victoria

Lake Victoria causes off-shore breezes like those at the coast. But the wind available, in general, is not as strong nor consistent as the wind at the coast. The wind energy decreases between April and July, especially around Kisumu and Kadenge. However, Lake Victoria winds are quite localised and places such as Rusinga Island and Muhoro Bay demonstrate usable winds year round.

Other Areas with Wind Potential

Wind machines have been installed successfully in many places in Kenya outside of the above three areas. The lower Tana River Basin experiences high winds during certain months of the year, as do certain parts of the Rift Valley. Below is a list of some windy places which have potentially good winds, but which require very complete site analysis.

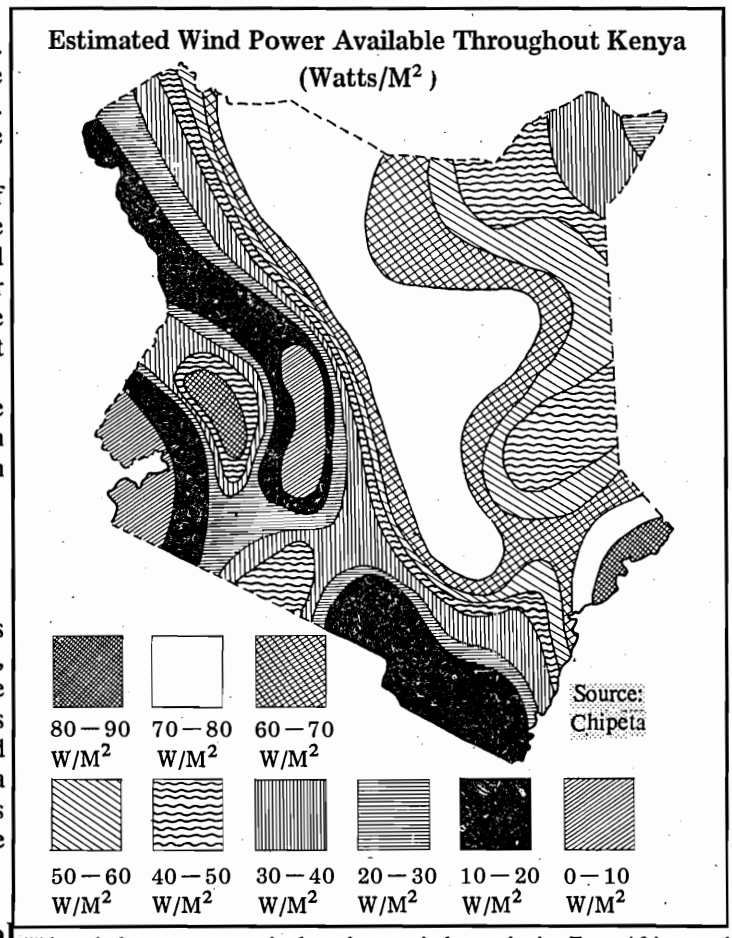
Nairobi/Ngong. Table 7.1 shows that Nairobi, Embakasi and Katumani (Ngong) have strong winds for much of the year. However, Dagoretti Corner, which is a few miles to the west of Nairobi, has much lower wind levels. The table also shows that winds are much lower than average between May and September for all three stations.

Keekorok. On the edge of the Rift Valley and in Maasai Mara, Keekorok exhibits medium strong winds for most of the year.

Garrisa/Lower Tana. There are strong winds in Garrisa and the Lower Tana River from May to October. However, during the remaining six months the winds are very weak. If wind is only needed for certain months (for example, to irrigate crops) wind machines might work here, but year round applications should be carefully studied beforehand.

Nanyuki/Rumuruti. This area has quite constant low to medium winds and many wind machines are currently pumping water for cattle ranches in the area.

Other areas which seem to have potential for wind machines are Eldoret, Amboseli and parts of Machakos.



This wind energy map is based on wind trends in East Africa and not actual data (compare with table on page 128). However, it can be used as a rough guide to wind activity in Kenya.

Table 7.1: Wind Energy in Kenya by Month

Station	Average wind speed at 10m height (m/s)												
	J	F	M	A	M	J	J	A	S	O	N	D	Year
North Western Kenya													
Katilu small-scale irrigation project, Turkana	3.2	3.3	3.3	3.0	3.3	3.2	2.8	3.2	3.5	3.5	3.2	3.2	3.2
Turkwel small-scale irrigation Project, Turkana	4.2	4.5	5.0	4.5	4.5	4.2	3.8	4.5	5.0	5.2	4.5	3.8	4.5
The Coast													
Magarini G.I.S.	4.1	4.0	2.9	3.2	4.0	4.0	4.1	4.1	3.9	3.6	3.1	3.4	3.7
Mombasa Airport Met. Station	3.6	3.7	3.6	4.6	4.1	4.3	4.0	3.9	4.0	3.8	3.0	3.2	3.8
Mtwapa Mtwempi Settlement Scheme	3.7	*	*	*	*	*	*	*	3.7	3.5	2.8	3.2	3.4
Lake Victoria													
Kadenge Hydromet 1st Order Station	2.7	2.8	2.8	2.1	1.9	2.2	2.0	2.4	2.9	2.2	2.3	2.4	2.4
Kisumu Meteorological Station	3.3	3.3	3.4	3.0	2.3	2.3	2.3	2.5	2.5	2.7	2.8	3.1	2.8
Muhoro Bay Hydromet 1st Order Station	3.5	3.4	3.6	3.1	3.1	3.1	3.1	3.8	3.7	3.7	3.3	3.3	3.4
Rusinga Island Hydromet 1st Order Station	3.9	4.0	4.2	3.3	3.2	3.0	3.4	3.5	3.5	3.6	3.4	3.6	3.6
Nairobi/Ngong													
Katumani experimental station	4.2	4.2	4.7	3.9	3.1	2.7	3.0	3.2	4.0	4.6	4.6	4.3	3.9
Nairobi Dagoretti Corner	3.6	3.4	3.4	2.5	1.7	2.5	1.5	1.7	2.0	2.9	2.9	3.2	2.5
Nairobi Embakasi Airport Met. Station	4.6	4.6	5.2	4.2	2.9	2.6	2.6	3.1	3.3	4.2	4.8	4.8	3.9
Other Areas													
Keekorok Hydromet 1st Order Station	3.3.	3.5	3.4	2.9	3.8	3.1	3.8	4.3	4.0	5.0	4.0	3.3	3.7
Galole Irrigation Scheme	1.9	1.8	1.9	2.2	3.2	3.5	3.7	3.9	3.8	3.4	1.9	1.6	2.7
Garissa Meteorological Station	1.8	2.0	2.0	2.4	3.6	4.2	4.6	4.5	3.9	3.0	1.8	1.6	3.0
Tana Irrigation Scheme (Hola)	2.1	2.2	2.5	3.0	3.7	4.2	4.3	4.7	4.2	3.7	1.9	1.7	3.2
Rumuruti M.O.W.	3.1	3.3	3.6	3.4	3.2	2.9	2.8	2.6	2.8	3.1	3.2	3.1	3.1

* Data unavailable

Source: SWD Wind Energy Development in Kenya, Vol. 2. 1981

Energy in the Wind

We have all watched trees or grasses moving as they are blown by the wind. Their motion is random, unpredictable and not very useful. However, when blown by the wind, a wind machine produces repeatable and thus *useful* motion. Most wind machines have a large *rotor* or wheel, which rotates when blown by the wind. This rotating motion is used to do work.

Wind machines are specially designed to effectively extract wind energy and change it into rotational energy which can be used to do useful work. By slowing down the wind that blows across them, wind machines "steal" part of its energy. After it passes over the rotor, wind has less energy than it had before, and the rotor has "stolen" that energy as it starts to rotate. The amount of energy that can be extracted from the wind depends on four major factors:

1. The *size* of the wind machine *rotors:* (turning blades of the wind machine)
2. The *speed* of the wind
3. The *density* of the air
4. The *efficiency* of the wind machine

Rotor Size

Wind is made up of molecules of moving air. These molecules move like the molecules in a stream of water, and it is the force of the air molecules "pushing" against the rotor that causes the rotor to turn. The area of the rotor that faces into the wind determines how much wind power can be captured. A rotor with twice as much surface area is struck by twice as much wind. Therefore, with constant winds, a rotor of 10 m^2 will produce twice as much power as a rotor of 5 m^2. *Large rotors produce more power.*

Wind Speed

The speed of the wind is the most important factor in determining how much power is available. Again, picturing wind as countless molecules of moving air, remember two key points. First, the faster *each molecule* is moving, the more energy *each molecule* gives up when it strikes the rotor. In fact, the energy in a single molecule is proportional to its speed squared. Considering this alone, if the wind speed

doubles its energy will increase by a factor of four. Secondly, the faster the wind speed, the more molecules that strike the rotor per second. It is easy to imagine twice as many molecules striking the rotor per second as the wind speed doubles.

It should thus be clear that an increase in wind speed will result in an increase in the *amount of energy* that each molecule gives to the rotor *and* an increase in the *number of molecules* that push against the rotor.

Because of the above factors, the power available from the wind increases very rapidly as the wind speed increases. Power available from the wind increases according to the *cube* of the wind speed (this is called the Law of the Cube). When the wind speed *doubles* (for example, from 10 kph to 20 kph) the power available increases by *eight* times. *Small increases in wind speed cause large increases in windmill power output.*

Air Density

The density of air is a measure of how "thick" the air is, or how many molecules of air there are per unit volume. The more dense air is, the more power is available from the wind. Air density is related to atmospheric pressure and temperature. Although air density changes slightly with altitude and temperature, the changes are quite small and are not an important factor in planning wind systems in Kenya. At an altitude of 1000 m, a wind machine can be expected to put out 9% less power than at sea level.

Wind Machine Efficiency

Whenever energy changes form, some is lost. This is also true with wind machines. The amount of energy lost depends on the *efficiency* of the wind machine. What percentage of the available wind energy does the wind machine actually capture as rotational mechanical energy and how effectively does it transfer the rotational energy into other useful work? Wind machines can trap a maximum of about 60% of the wind's energy as some energy always remains in the wind passing through the rotors. Some energy is also lost as friction in the transmission and gears of the wind machine. Most wind machines have efficiencies that range between 20% and 50%. In other words, most potential energy in wind is usually lost, and not transformed to rotational energy by the rotor.

Wind Power Equation

The power that can be extracted from the wind as explained above is summarised in the mathematical equation below:

$$P = \frac{1}{2} q A V^3 E$$

In the equation,

P = Power extracted from the wind by the wind machine in watts.

q = Density of air (kg/m^3)

A = Surface area of rotor (m^2)

V = Wind speed (m/s)

E = Efficiency of wind machine

In summary, the equation gives us four principles:

1. Power from the wind machine is proportional to the area swept by the wind machine blades (i.e. the size of the rotor).
2. Power from the wind machine is proportional to the *cube* of the wind speed.
3. Power from the wind machine is proportional to the density of the air.
4. Power available from the wind machine depends on the efficiency of the wind machine.

Evaluating a Wind Site

A major cause of dissatisfaction among those that use wind power machines is improper site selection. Careful site selection for a wind machine, done before the machine is bought, will ensure that much time and money are not wasted. A good siting of a wind machine will ensure that the most power is obtained for the least installation cost. A proper site will also minimise maintenance costs and damage risks.

Even before one attempts to measure wind resources, one must ask what one's power needs are. How much water needs to be pumped? How much electricity is needed? Once one has a good idea of what kind and how much power is needed, one should then go to the wind power site and estimate how much power is available. Finally, one should examine the available wind machines and determine which type and how large a machine is needed to fulfill the power requirements given the site's available wind energy. If the wind speed, V, and the windmill efficiency, E, are known, the wind power equation can be used to determine how large a rotor area, A, (and thus how large a wind machine) is needed to get the desired power, P.

Finding Information About Local Winds

In order to choose the right wind machine (or whether one will be useful at all), as much information as possible about the wind in the area must be assembled. Information about local winds can be gathered in a variety of ways.

The first place to check is the local meteorological station (if there is one within 50 km) or airport. These people have spent years collecting information about the area's weather. They have useful data about the wind direction and speed, and will be able to give information about local prevailing winds and seasonal changes in the wind.

A second source of information about winds is the local people. If you are not familiar with the winds in the area you wish to build a wind machine, the local people may be your best source of information. They will know about the seasonal wind changes, the daily

wind changes and local wind irregularities which are important to consider in planning stages. Of course, the best local person to see is someone who already has a wind machine, if there is anyone nearby.

A third source of information about general wind patterns is the vegetation of the area. Trees and bushes are often bent over in the direction of the prevailing wind. This tendency of trees to bend in the direction of prevailing winds is called *flagging* (see photo page 124). Flagging can also indicate how *strong* the winds are.

The Site Survey: Information to Collect

The local weather station, the people and the vegetation will give you a good idea what winds are like. But, remembering that a *small increase* in the amount of wind will give a *large increase* in the amount of power available, it is important that a complete wind study be carried out. Most experts recommend that the wind be studied in a few sites for 3 months. The best site among those studied can then be selected.

Final selection of a wind machine site involves many considerations. If the wind machine is to pump water, putting it on top of a large hill (even though there is a lot of wind atop the hill) means it would have to pump water from a deeper well. If the machine is to generate electricity, putting it far from the place where the electricity is *needed* might be expensive. The work that the machine is to do helps to determine the best site for that wind machine.

A windmill should be able to capture the maximum possible wind energy, and this should be kept in mind during site selection. There are a number of local topographical features that effect the flow of the wind that must be considered.

In general:

-- Wind machines should be mounted as high as possible on a tower because wind speed always increases with height.

-- Wind machines should be mounted 150-200 meters away from the nearest obstruction (i.e. trees, buildings), especially when the prevailing wind comes from that direction.

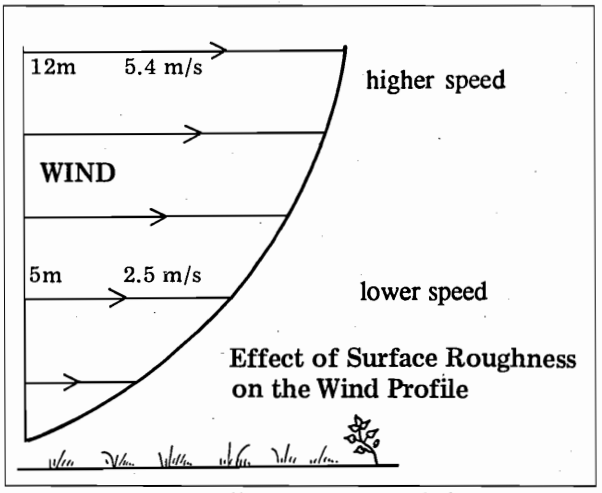
Flat Terrain

If the wind machine is to be built on flat terrain, (i.e. if there are no hills or valleys in the direction from which the prevailing winds blow), there are two considerations:

What is the surface roughness of the area?

What barriers affect the free flow of wind?

Surface roughness slows down the wind near the ground. Smooth surfaces such as the ocean and low grass allow the wind to pass swiftly. However tall

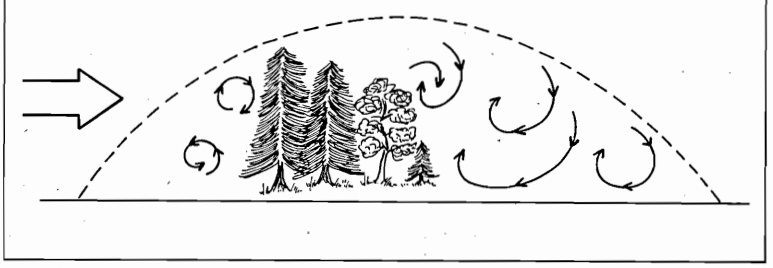


Effect of Surface Roughness on the Wind Profile

crops, woods or small towns cause turbulence and loss of wind speed as it passes over them. In order to take advantage of winds near towns or forests, the wind machine tower must be 6-10 metres *above* the level of the forest canopy or rooftops. The more the surface roughness, the higher the tower needs to be.

Barriers, such as buildings and shelter belts of trees, block the wind and produce disturbed areas of airflow downwind. When putting up wind machines, areas of

Turbulence around Tree Barriers



disturbed airflow should be avoided. In general, wind machines should be located a distance10-20 times the height of the nearest barrier *downwind,* and the tower should be *twice the height* of the nearest barrier.

Non-flat Terrain

Non-flat terrain presents more complex problems in wind machine siting as topographical features affect wind flow in much more complicated ways than surface roughness or barriers. Therefore, wind power sites in a hilly areas need to be evaluated with special care. Nevertheless, non-flat terrain may present certain *benefits* to a wind power site:

Ridges, hills and isolated mountains. These topographical features act as huge towers, placing wind machines in ideal high wind areas. Wind *accelerates* as it moves up hillsides, and is usually at a higher speed at the top of a ridge than the wind below. Wind machines should, when possible, be located at the *top* of ridges and hills.

Passes and low spots in escarpments. As prevailing winds blow toward escarpments, they are *funnelled* through passes and low spots at *increased speeds.* Wind machines erected in such places will perform optimally.

Valleys. Unless a valley is very narrow and oriented so that the prevailing wind is "squeezed" through it, as above, valleys can be expected to have less wind activity. Therefore valley bottoms should be avoided as potential sites.

Hazards to Wind Machines

The following list describes some major hazards that can knock down, break rotors, cause rapid corrosion or seriously damage expensive wind machines. They should be kept in mind during planning, in order that the wind machine is built, protected or situated to avoid them.

Turbulence is rapid changes in wind speed and direction which cause stressful vibrations to the machine. Surface roughness, barriers and non-flat terrain can all cause turbulence.

Extremely highspeed winds may damage the wind machine or knock down the tower.

Floods and landslides can wash away the foundations of the tower.

Salt spray causes rapid rusting of the machine.

Blowing dust or sand scrapes paint off the machine and clogs the bearings.

Large birds may fly into and damage the rotors.

Wind Study

The following data needs to be collected during any wind study. Tools which are useful for collecting the information are also described here.

Temporal Wind Patterns

During the day. How does the wind change in the course of 24 hours? Several measurements should be taken in the day (and night) to find the general daily wind pattern. Measurements taken should include *wind speed* and *wind direction.*

During the year. How does the wind change from month to month? Because in most sites the wind changes from season to season, it is important to find out during which seasons there is little wind. Monthly wind speeds are calculated by taking the average of the daily windspeeds over the month. Changes in the prevailing direction from which the wind blows should also be listed.

Lull periods. How often are there no winds? How long do the periods of no wind last? This data is important in sizing the required energy storage systems.

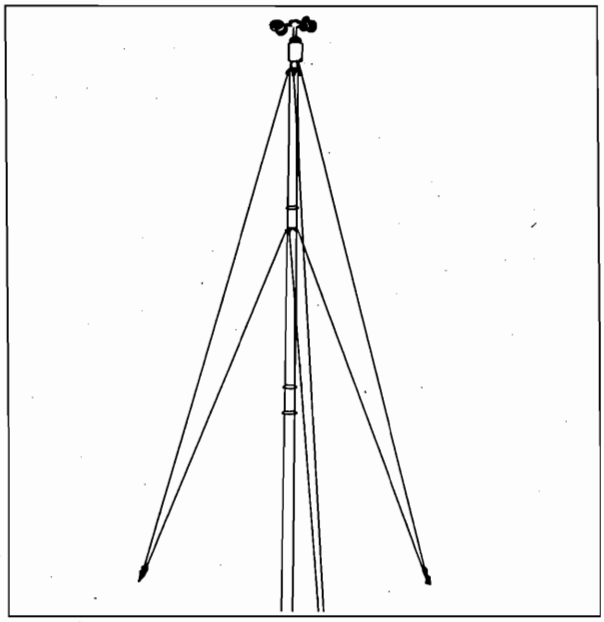
Frequency Distribution of Wind

How many hours per month does a certain wind speed occur? Remember that doubling the wind speed will increase wind power by eight times. This means that if the wind blows at a high speed for only one hour each day, and at a low speed for the rest of the time, the power available during that *one* hour might be enough to accomplish the desired work.

The average wind speed for a location gives a very rough estimate of the wind power available. However, if one knows that in each day the wind can be expected to blow at a certain speed for two hours and at another speed for one hour (etc.), a *very accurate* estimate of the power available can be made.

Tools for Measuring Wind

The importance of measuring the wind speed at the site *as accurately as possible* cannot be overemphasized. Proper tools will obviously make the task easier. Manufacturers of wind power machines will be able to help evaluate a site and may have the



Cup anemometer on a tower.

tools needed to do a complete site evaluation. The following is a list of useful wind measuring tools:

Anemometers are tools used to measure wind speed. Usually, they count the number of revolutions of a rotor spinning in the wind over time. *Cup anemometers* are mounted on poles at weather stations to find the average wind speed. *Hand-held anemometers* are cheaper devices that can be carried to the site and are hence the most appropriate tools for local wind surveys.

Wind speeds measured 2 m above the ground will give a low indication of a site's wind potential because *the wind speed always increases with height.* Proper measurements are taken from 10 metres (which is about the height of a wind machine tower). Wind speed is commonly measured in metres per second (m/s).

Compasses help to determine the direction from which the wind is blowing. Every time a wind speed measurement is made, a wind direction measurement should also be made (i.e. wind is blowing at 2.5 m/s *from the west*).

The Beaufort Scale. If an anemometer is not available, a wind study can still be made using the Beaufort scale to estimate the wind's speed. The scale is simply a table (see next page) which relates the behavior of smoke, trees, flags, and other landmarks to known wind speeds. Daily readings are taken as with an anemometer, using the listed weather features (i.e. smoke raises straight up -- calm) as guides for approximate wind speeds. The Beaufort scale is not very accurate, but is sometimes the best wind speed scale available.

Table 7.2 : The Beaufort Scale

EFFECT CAUSED BY WIND	BEAUFORT NUMBER	DESCRIPTION	WIND SPEED M/S	WIND SPEED KM/HR
Still, smoke rises vertically	0	Calm	0-0.2	0-2
Smoke drifts, flags remain still	1	Light air	0.3-1.5	2-5
Wind felt on face, leaves rustle, flag moves	2	Light breeze	1.6-3.3	6-12
Leaves&twigs move constantly, flag extended	3	Gentle breeze	3.4-5.4	13-20
Raises dust & paper, moves thin branches	4	Moderate breeze	5.5-7.9	21-30
Small trees begin to sway	5	Fresh breeze	8.0-10.7	31-40
Large branches move, umbrellas hard to control	6	Strong wind	10.8-13.8	41-52
Whole trees move, resistance to walking	7	Stiff wind	13.9-17.1	53-63
Breaks twigs off trees, hard to walk	8	Stormy wind	17.2-20.7	64-77
Blows off roof tiles	9	Storm	20.8-24.4	78-90
Trees uprooted, houses damaged	10	Heavy storm	24.5-28.4	91-105

Source: *Energy Primer*, Ed. R. Merrell, Dell Publishing Co, 1978

Conclusion

The above information introduces the process of selecting and studying a wind power site in order to determine whether a wind machine will be economical. Because wind machines are expensive investments, complete site studies should *always* be carried out. The following steps summarise the process of choosing wind machines and sites, and if followed, will ensure that the machine performs optimally. Each of the steps should be taken with assistance from a wind machine manufacturer or some other knowledgeable person.

1. Determine the amount and type of power needed.
2. Select several sites which seem to have high wind potential.
3. Study the wind at each site to find the power available and whether it is consistent.
4. If the wind sites consistently have enough power, choose the *best* site among them.
5. Select a wind machine of a size and type that fits the available winds and power needs of the site.

A Short History of Wind Power

Wind Machine Development

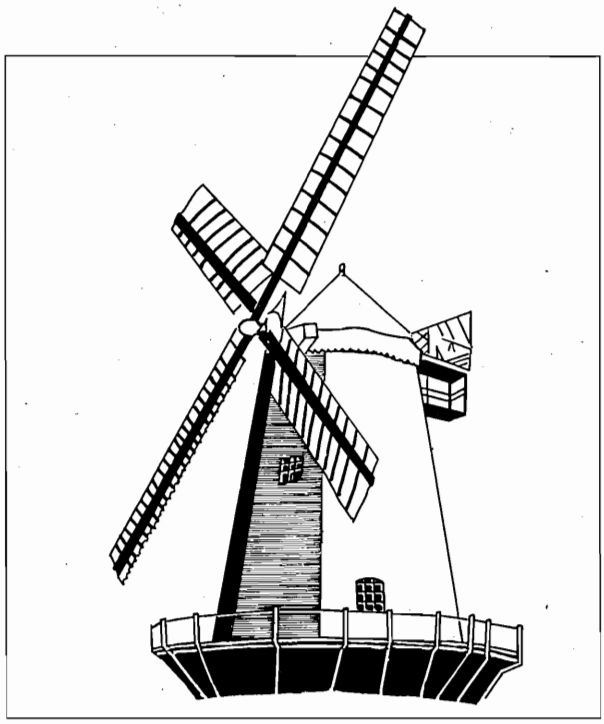
Man started making use of the wind during ancient times. Wind was first used to power ships and, as sailing ships were improved, new uses of the wind were discovered. North Africans were the first to harness the wind. The Egyptians built ships with sails as early as 2800 B.C., and this practice quickly spread to other cultures. Evidence shows that the earliest *windmills* were built by the Chinese to lift water into rice fields. The Persians were also building simple windmills as early as two centuries B.C. By 700 A.D., vertical shaft windmills called *panemomes* turned grinding stones that milled flour throughout the Middle East. The Moslems helped spread windmill designs as far as Turkey and Crete.

The Crusaders are credited with bringing windmill technology back to Europe when they returned from their wars in the Middle East. Starting in the 12th century, the Dutch developed large horizontal shaft windmills which they put to work pumping water, grinding grains, and running sawmills and other machines. Windmills spread to other parts of Europe during the Middle Ages and improvements were added steadily to the designs.

In 1750, an important invention greatly improved windmill technology. This device, called the *fantail*, enabled windmills to turn to face the wind automatically whenever the wind changed direction. Before, the windmill operator had to turn the rotors to face the wind himself. In the Netherlands, improved windmills with fantails flourished, pumping water out of flooded land and making it useful for agriculture.

As people travelled across the oceans to the Americas, the Carribean (and later Australia), they carried the windmill technology with them. By 1800, there were many windmills of the familiar Dutch design operating in America and in the Carribean Isles.

Immigrant farmers in the USA quickly took advantage of the large amounts of wind available on the North American plains. In 1850 the *American Farm Windmill* was invented to pump water from deep wells for domestic use, cattle raising and irrigation. Farmers all over the dry parts of the American West relied exclusively on *hundreds of thousands* of windpumps during the development of Canada and the USA.



Dutch windmills in the Netherlands were used extensively to pump water from flooded agricultural lands.

American Farm Windmills still supply a great portion of the water needs of cattle and sheep ranchers in North America, Argentina and Australia.

Around the turn of the century, Danes and Americans developed wind powered electric generators which could supply electricity in remote windy areas. There was soon an active market for wind-powered generators in rural Europe and America. Farmers in the American Great Plains (who already had wind-powered water pumps) were especially interested in using wind generated electricity to power lights, radios and small appliances in their homes. Up until the 1930s, there were thousands of wind-powered rural homes in the USA. With the advent of rural electrification programmes, when mains electricity became cheap and plentiful, most wind generators were abandoned in Europe and America.

Although research activities continued in many countries, the use of wind power declined with the introduction of cheap electricity and petroleum after the 1940s. During the oil crisis in the 1970s people again turned to wind energy as an alternative to limited conventional sources of energy. At present, countries in both the "developing world" and "developed world" are again seeking to harness the wind for their energy needs. Californians, for example, installed over 1000 megawatts of wind-generated electricity (almost *twice as much* as Kenya's 1987 total electric production) between 1975 and 1985. The Netherlands still are among the world leaders in wind energy technology.

Wind Machines in Africa

Certain parts of Africa with large wind potential have been making use of wind energy for some time. South Africa, with no known oil reserves and the highest wind potential on the continent, had more than 150,000 windmills in operation as of 1960. These windmills are used mostly for pumping water on cattle ranches and remote homesteads.

Cape Verde, a group of islands off the west coast of Africa, has also made a sizeable use of wind energy (considering their small size). Sao Vicente, the largest island, has more than 100 water pumping wind machines, some locally produced and others imported. Sal has about 20 locally made wooden windmills which pump salt water into evaporation ponds. Boa Vista uses the same type of wooden windmills to pump water for irrigation.

Other countries are now developing their wind power resources. For example, Zambia, Botswana and Ethiopia use windmills for water pumping while Tanzania has also developed wind machines for grinding maize in rural areas. Zimbabwe has at least two active windmill manufacturers.

Wind Machines in Kenya

Wind machines are not new in Kenya. Windpumps, mostly of the multiblade American Farm Windmill design, have been supplying water in Kenya for almost one hundred years. These machines were first imported to Kenya by colonialists before independence and used to pump water in settled regions such as Nanyuki and Eldoret. Some of these windmills are still working after many decades.

During the 1960s, when cheap oil became available, most windmills were replaced by diesel engines. After independence, spare parts for windmills were not easily available and few people had the skills needed to fix windmills. Furthermore, importing new windmills was very expensive. Use of windmills thus declined and many broke down or stopped working.

The rise of fuel prices during the 1970s made diesel powered pumps much more expensive to run. During this period quite a few of the broken down imported windpumps still standing were *restored* as local people began to recognize the potential of wind power. At the same time, many government and development agencies began to investigate increased use of wind power in Kenya.

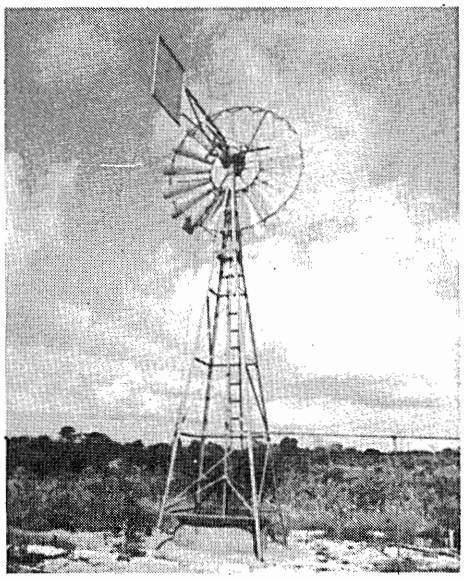
Various wind projects were started by the university, churches, volunteers, private individuals and development agencies across the country in the 1970's. Most had a goal of building windmills with local materials in order that the country would not have to rely on expensive imported types. However, most of these projects were unsuccessful for several reasons:

1. Windmills were not properly built, and new designs were introduced before they had been refined or tested.
2. People underestimated the complexity of windmills. Windmills require a complete understanding of certain principles of mechanics, as well as a decent metal-working shop, to be well-designed and built.
3. After they were built, windmills often were not maintained. Sometimes local people were not sufficiently trained to maintain the windmills.

4. Projects were poorly planned. Sometimes windmills were built without considering what they would be used for. Sometimes the people who were supposed to benefit from the windmills were not involved in the project planning.

This does not mean that there were no successes. During the early 1980's the government sought the assistance of a wind expert group from the Netherlands (called the Steering Wind Committee) to evaluate past and on-going wind projects in Kenya and to suggest the best courses of action. This group made a complete study of windmill projects in Kenya, and helped the government choose those that were worthwhile. With assistance from various agencies (notably Intermediate Technology and Development Group) good quality wind machines were developed, and several manufacturers have progressed rapidly.

By 1986, there were over 200 working windmills in Kenya (almost all of them used for pumping water). Several companies have perfected windmill designs and sell them to ranches, missions, settlement schemes, lodges and schools. Bobs Harries Engineering in Thika had sold over one hundred *Kijito* windpumps as of 1987 and Pwani Fabricators (see photo below), in Mombasa, had sold over 50 pumps. Meanwhile, Sound Communications, a company based in Nairobi has begun making and marketing *wind generators*.

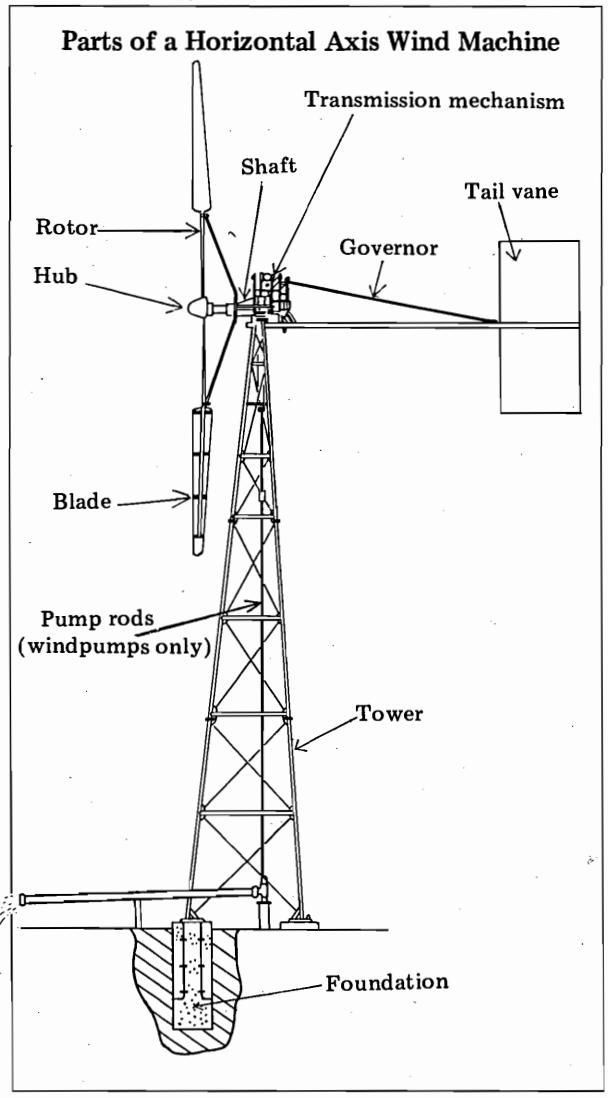


Locally manufactured windpump in Kilifi district.

Wind Machines

Parts of a Wind Machine

Wind machines are not simple devices, and anyone interested in building or buying one should be warned. The process of *harvesting* the wind, making its energy available in a useful form, and supporting all of the involved mechanisms is complicated. Each part descibed below must be built both to withstand constant abuse from the forces of the weather and to perform in harmony with the other parts of the machine.



The Rotor and Shaft

The *rotor* (or *impeller*) is the moving part of the wind machine that slows down the wind and captures part of its energy. Different types of wind machines have different types of rotors. High speed wind machines used for generating electricity have rotors with two or three thin blades shaped like the propellers of aeroplanes. Low speed wind machines used for pumping water have rotors with many large blades. Rotor blades are made from wood, metal or fibreglass. Some windmills have rotor blades, called *sails*, made from canvas.

The rotor is attached to the main *shaft* at the hub assembly. The shaft turns about its axis as the wind blows the rotor and thus transforms wind energy into rotating mechanical energy which can, in turn, be used to do work.

Larger rotors harvest more wind energy. In areas where there are constant low to medium speed winds, large rotors make the best use of that wind. Wind machines are often identified by the size of their rotors (e.g. A 6.1 m *Kijito* windmill has rotor diameter of 6.1 m).

Transmission Mechanism

Power from the rotor and turning shaft is transmitted to the application by the *transmission mechanism.* The type of transmission mechanism depends on the application of the wind machine (i.e. pumping water, generating electricity, grinding maize, etc.). In the case of a wind pump, power from the turning shaft is transmitted, by *gears* or by a *crank arrangement*, to pump rods which move up and down, driving the pump in the borehole below. For grinding grains, millstones are turned by gears, belts or chain drives attached to the main shaft. In the case of high speed wind machines which generate electricity, there is often no need for a transmission device because the spinning shaft is the same as the shaft of the generator.

Steering and Storm Protection Mechanisms

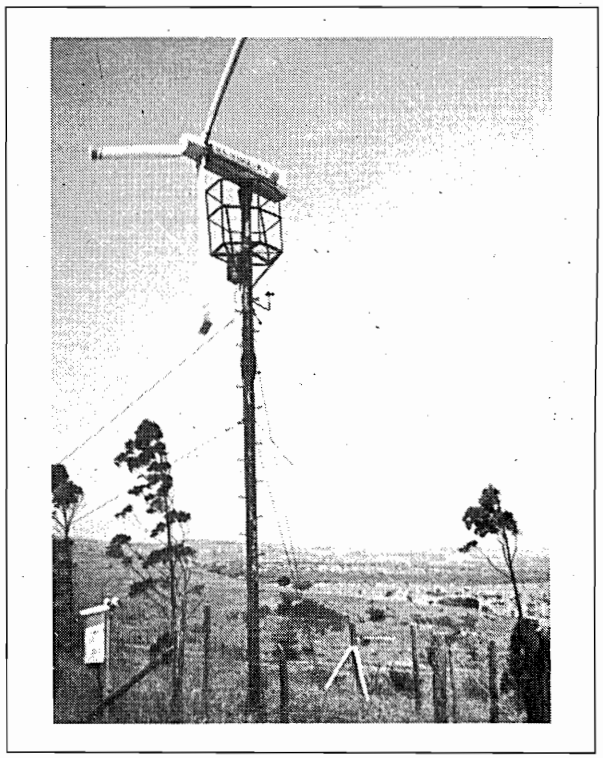
Because the wind is constantly changing direction, the rotor must also constantly turn to face the direction from which the wind blows. The *steering mechanism* keeps the rotor aiming into the wind automatically. The most common type of steering mechanisms is the *tail vane*, a flat piece of metal or wood behind and at a right angle to the rotor. As the wind blows against the tail vane it turns itself to a position parallel to the wind flow, thus orienting the rotor so that it faces the wind. Tail vanes *steer* wind machines in the same way rudders steer airplanes. *Vertical axis* wind machines (see page 138) do not require steering mechanisms because they can accept wind from any direction.

All wind machines require some sort of protection against high winds. Very strong winds will cause the rotor to spin too fast, making the machine vibrate or wobble until breakage occurs. *Governing* (or *storm protection*) devices protect wind machines from damage by high winds. Some machines have governing devices that turn the rotors out of the wind (either by tilting the rotor up or by turning it sideways) when the wind blows above a certain speed. Other machines have brakes which slow down or stop the rotors during high winds. Still other machines have blades that can change their angle to the wind (pitch), and thus reduce the force against them during high winds.

Towers

Towers support wind machines and put them high in the air. Near the ground, winds are *slower* and *more turbulent* than winds high above the ground. In fact, there is often two times more wind at 10 m than there is at 2 m. Towers place wind machines in quality winds that are less affected by surface roughness or barriers.

Towers must always be built to support the weight of the wind machine and to withstand the full force of high winds blowing against the wind machine and the tower itself. They are typically constructed of strong metal bars in the shape of a very tall pyramid with a foundation anchored in concrete. They may also be made out of wood, or for small machines, of a single steel pole with guy wires. *Guy wires*, used to give tall towers extra stability, are strong cables attached to the tower and anchored in the ground. They ensure that the tower does not move or shake during high winds.



5kW wind generator mounted on pole-type tower with guy wires (Ngong).

Types of Wind Machines

Many types of wind machines are in use today. As with waterwheels, these can be divided into two general groups: *horizontal axis* and *vertical axis* wind machines. (Axis refers to the main shaft turned by the rotor).

Horizontal Axis Wind Machines

Horizontal axis wind machines have shafts which are parallel and rotors which are perpendicular to the ground and wind direction. Almost all of the wind machines found in Kenya are horizontal axis type. Because 100% of the surface area of the rotor faces the wind, this type of wind machine uses the wind very effectively. Horizontal axis wind machines are, in general, more efficient than vertical axis wind machines, and thus they produce more power for the same wind.

However, they are more complicated than vertical axis wind machines because of their steering and power transfer mechanisms. Furthermore, their blades are subject to large centrifugal forces during high winds, and rapid changes in wind direction cause much stress to the machine itself. Most horizontal axis wind machines fall into one of the following groups: *multiple-bladed windmills, sail windmills/traditional windmills, or high speed rotors.*

Multiple-Bladed Windmills. By far the most common type of wind machine in Kenya and abroad, multiple bladed windmills are used primarily for pumping water. The many blades of these windmills cover most of the

wind-swept area of the rotor, channelling wind in the same way that turbines channel water (this is called *the cascade effect*).

Because of the large surface area of the windmill rotor, these machines have a high *starting torque*, or more simply, enough *power* to pump water even from deep boreholes when the rotor starts turning. Multiple-bladed windmills have fairly simple design and construction requirements and long lifetimes. It is not uncommon to see windpumps that have pumped water for 30 years or more.

These windmills turn slowly, and hence cannot be used for high RPM needs (applications that require many revolutions per minute) such as generating electricity. They also put a lot of stress on the tower (because of the high rotor surface area) during high winds, and thus require well-built towers.

Example: *Kijito* Windpumps

Kijito windpumps (see photos page 24, 127, 148) are direct drive multiple-bladed windmills developed in conjunction with the British Intermediate Technology and Development Group. They have incorporated new engineering features which make them more efficient and maintainable than older multiple-bladed designs. The rotor design enables the machine to start pumping in winds as low as 2 m/s. Power from the main shaft is transmitted to the pump via a *crank and rocker transmission* and pump rods that avoid maintenance problems caused by gears. Kijito bearings need only be greased twice a year.

The tail vane keeps the rotor aimed into the wind *and* also acts as a *governing mechanism.* When wind speeds exceed 12 m/s , the tail automatically turns the rotor edgewise into the wind. If the wind speed continues to increase, the rotor stops turning completely, but once the wind slows down, the tail opens out and the machine starts pumping again.

Kijito towers are 10 metre tripod-type made from three sections of heavy gauge tubular steel. They are hinged at the base to allow the whole machine to be assembled on the ground during installation and then winched into position with the help of cables.

Bobs Harries Engineering, Ltd. has been working on the *Kijito* design since 1979, and has exported windpumps to Uganda, Tanzania, Nigeria and the Sudan. Today, they are developing a smaller and cheaper windpump, called the *Wananchi* (see photo page 124), which will serve the needs of small farmers.

Table 7.3 indicates the amount of water pumped per day in *light, medium* and *strong* wind regimes, assuming that the pump cylinder is properly matched to the rotor and pumping head. *Example:* With a 40m head and medium strength winds (3-4 m/s), a 6.1 m windpump can be expected to pump 27 cubic metres (27,000 litres) of water per day (see table).

Table 7.3: *Kijito* Windpump Performance Table

CUBIC METRES OF WATER DELIVERED PER DAY IN LIGHT (2-3 m/s), MEDIUM (3-4 m/s) AND STRONG (4-5 m/s) WINDS

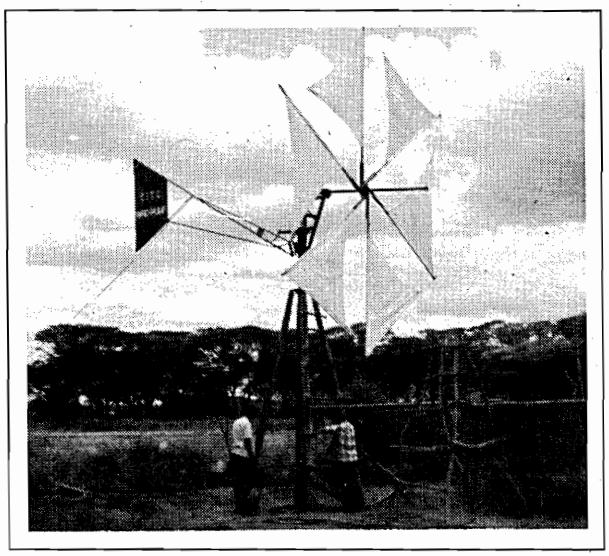
ROTOR SIZE	3.7m			4.9m			6.1m			7.4m		
Wind Speed (m/s)	2-3	3-4	4-5	2-3	3-4	4-5	2-3	3-4	4-5	2-3	3-4	4-5
HEAD (m)												
10	10	28	59	21	71	150	39	107	227	61	167	354
20	5	14	29	10	35	75	19	53	113	30	83	177
40	-	7	15	5	18	37	10	27	57	15	42	89
80	-	3	7	3	9	19	5	13	28	8	21	44
120	-	-	5	-	6	12	3	9	19	5	14	29
160	-	-	4	-	4	9	-	7	14	4	10	22
200	-	-	3	-	-	7	-	5	11	-	8	17
240	-	-	-	-	-	6	-	-	9	-	7	14

Source: Bobs Harries Eng. Ltd., Leaflet, 1987.

Sail and traditional windmills have been used for centuries all over the world for low-lift pumping, grain grinding and milling. They have from 4 to 8 blades, or "sails" which turn according to the *air foil principle* (i.e. currents of wind move across the rotor blades' air foil and generate *lift*).

The most attractive feature of these windmills is that they can be built locally. Constructed with whatever materials are available (wood, bamboo, scrap iron, old car axles, canvas, etc.), these are the least expensive tools for harnessing wind power. The Dutch Windmill was crucial to the development of industry in the Netherlands and England. American farmers built hundreds of low head water pumping windmills from scrap wood on their land one hundred years ago. China, Thailand, Greece and Portugal now have large numbers of these locally made windmills pumping water for irrigation of crops. No matter where and when, the most successful of the above windmills are *user-built.*

At present, many developing nations, including



Water-pumping sailmill and water tank, Turkana district. Note the canvas sails on the rotor.

Kenya, are making efforts to develop these cheap windmills. Especially popular is the *Cretian windmill* (see photo) which has canvas rotor blades. Many of these locally built machines have failed in projects in Ethiopia, Kenya and elsewhere for reasons already described. The fact that they are less expensive than other wind machines does not mean that they do not need to be *maintained*. On the contrary, the reliability of locally built windmills is especially related to the care, maintenance and local understanding that they receive.

High-speed rotor wind generators are used to generate electricity. Their rotors have two or three thin blades similar to propellers of aeroplanes. As the name indicates, the rotors turn very quickly, and they generate power quite efficiently. The rotor shaft of most wind generators is also the shaft of a *generator* , and as it revolves it turns magnetic coils, producing large amounts of electricity given sufficient winds. The thin rotor blades use very little material (they are made of fibreglass, metal or carved wood) and do not put a heavy load on the tower. In windy, remote areas, wind generators are an excellent source of electricity.

Like solar electric systems, wind generators produce electric power that must be *stored* for times when power is not being produced. Therefore, generators usually charge batteries so that electric power is available when the wind is not blowing. Also like solar and hydro electric systems, wind generator systems require some form of *control system* to insure that the batteries and appliances are not damaged by the changing power output.

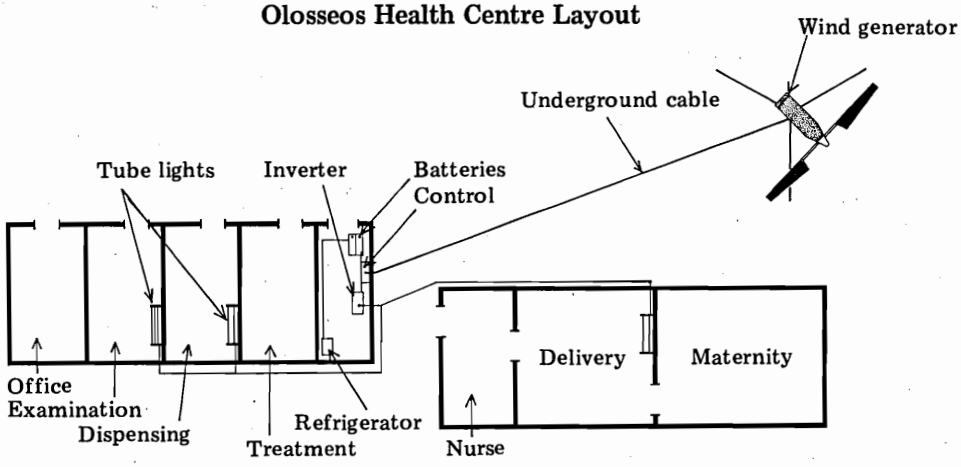
Because of their low starting torque, wind generators cannot easily be used for mechanical applications. Furthermore, the blades must be carefully designed or they will wobble, vibrate and break off. Hence building high speed rotors requires a knowledge of aerodynamics. In general, wind generators are expensive pieces of equipment. Finally, it should be noted that high speed rotors require somewhat higher wind speeds than other horizontal axis windmills to operate efficiently.

Example : Sound Communications Wind Generators

Although as of 1987 there were few wind generators operating in Kenya, at least one company is putting forth efforts to develop locally-made machines. Sound Communications, under the direction of Mr. Samuel Ngugi and with assistance from Kenya Industrial Estates, has installed wind generators in Nairobi, Machakos, and Olosseos, near Ngong. So far the company has produced models rated at 1 and 5 kilowatts (maximum output). At Olosseos, the 5 kw generator charges batteries which power the lights and refrigerator of the Masai Rural Health Centre (see diagram below & photo on page 24 & 135). Meanwhile, a demonstration generator at Sound Communications (seen from city stadium roundabout, Nairobi), charges batteries and heats water through resistors.

As wind resources are quite high in many areas located far from the grid, wind generators such as these have a good potential for rural power supply. Sound Communications hopes to work with the government on power supply projects in the near future.

Olosseos Health Centre Layout



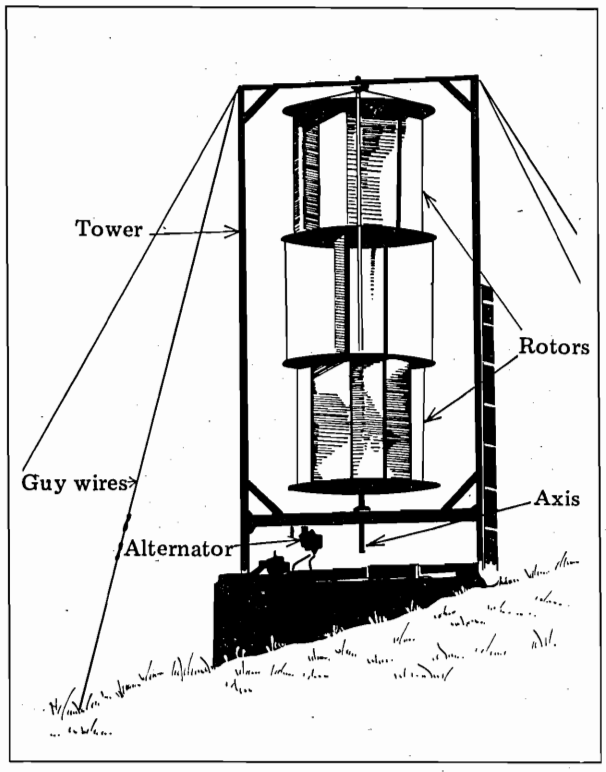
Vertical Axis Wind Machines

Vertical axis wind machines have shafts which are perpendicular to the direction of wind flow. Although very few vertical axis wind machines have been used in Kenya, they have several advantages which make them locally attractive.

The first wind machines, used by the Persians several centuries before Christ, were vertical shaft wind machines called *panemones* used in flour grinding mills. The wind spun 4 to 8 sails around a vertical axis which was attached directly to a grinding stone below it.

Vertical axis wind machines are often simple to build from local materials. Requiring no device to aim them into the wind, they generate power equally well no matter what direction the wind blows as their rotors accept gusts of wind from any direction.

The ability of vertical axis rotors to accept wind from all sides is also a disadvantage as it makes these rotors difficult to govern during strong winds. Also, because only half of the rotor surface is pushed by the wind at any given time, vertical axis machines are usually less efficient than horizontal axis wind machines (this is not true with the *Darrieus rotor*). Two modern vertical axis wind machines are described below: The Savonius Rotor and the Darrieus Rotor.



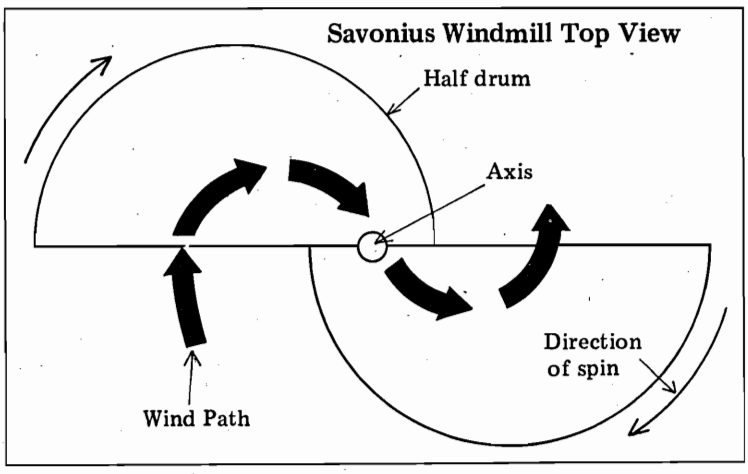
Drawing of a Savonius rotor with 3 stacked "S" rotors and an attached alternator for producing electricity.

Savonius rotors are probably the cheapest and simplest windmill designs. The rotor is constructed from two halves of a 220 litre drum which have been offset and mounted on a vertical shaft (see diagram). No matter from which direction the wind is blowing, it will always turn the "S" shaped rotor.

At the low speed which they operate, these wind machines are most applicable to high-torque applications such as pumping water or operating machinery. Electricity can be produced by attaching the vertical shaft to an alternator using geared chains. Wind power harvests are increased by stacking several "S" rotors on the same vertical shaft.

Savonius rotors operate less efficiently than horizontal axis wind machines because only part of the rotor faces the wind. Also, the Savonius rotor cannot be easily turned out of high winds, and thus is difficult to control in stormy weather (although Kenya is not known for such high winds). For this reason, and because the rotor presents a large surface area to the wind, towers for Savonius rotors must be especially sturdy (supported both above and below the machine). In practice, Savonius rotor powered water pumps have had problems with power transmission to the pump.

There have been more than a few arguments about the utility of Savonius rotors, and many experts are convinced that they are little more than toys. However, others have successfully employed them and claim that there is no cheaper windmill. A model of a Savonius rotor can be made quite easily by cutting a tin in half (along the vertical axis), off setting the two halves, and mounting the them on a shaft.

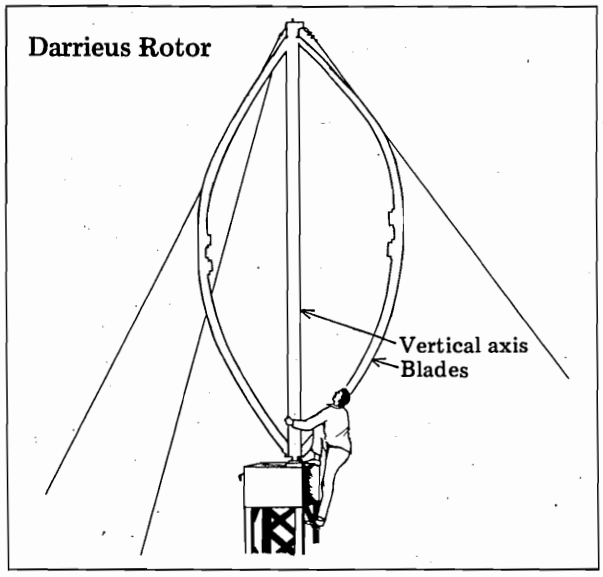


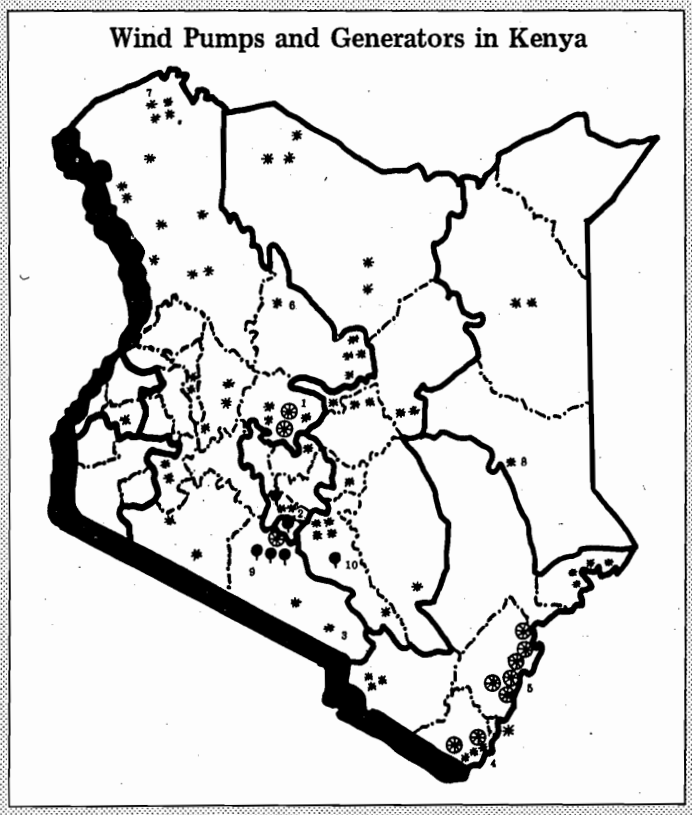
Darrieus Rotors combine advantages of vertical axis wind machines with advantages of high speed rotor horizontal axis machines. A Darrieus rotor is constructed with 2 or 3 wing-shaped blades that either *bend* in an arc from the top to the bottom of the shaft or are straight and *parallel* to the shaft. The blades, as do high speed rotors, have an air foil shape that produces *lift* like the wings of an airplane when the wind blows across them. As the wind blows the lift force pulls the rotor blades forward at a speed which is much faster than that of the wind. The high speed at which Darrieus rotors turn makes them best suited for electrical generation. An important feature of this rotor is its high efficiency.

Construction of a Darrieus rotor is comparatively simple as long as the designers/builders have a knowledge of how the rotor works. Its fairly recent design can

be adapted to use various local building resources (such as wood or canvas rotors). Presently, the design is still in the experimental stage, and there are few practical models on the market.

Darrieus rotors, unfortunately, do not usually start spinning by themselves. They must be spinning at a certain speed before the *lift* that causes the rotor to turn is produced. Also, the rotors will stall (i.e. lift will no longer be produced) when there is a lull in the wind and stop spinning. Darrieus rotors must thus be *started* (by motors or some other means) at first when the wind is blowing at sufficient speed and *restarted* again after each time there has been a lull. Darrieus rotors should only be built where there are regular medium to high winds. There is a Darrieus rotor on display at Mombasa Polytechnic.



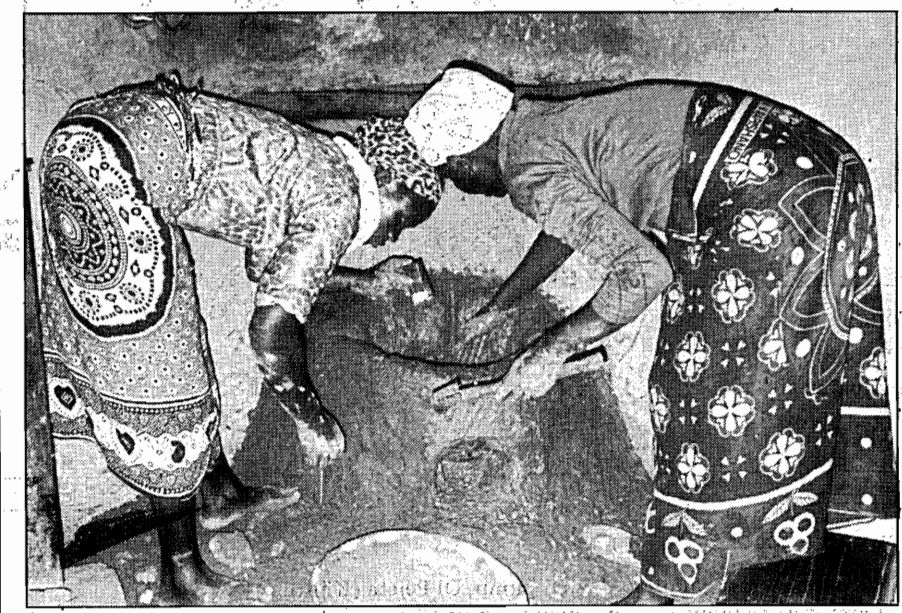


Legend

- ⊛ 5 Wind pumps
- ✳ 1 Wind pump
- ♀ Wind generator

Example Projects

1. Livestock water supply — Wind pump, Ol Pejeta (Kijito)
2. Farm water supply — Wind pump, Thika (Wananchi)
3. Tourism water supply — Wind pump, Amboseli (Kijito)
4. Village water supply — Wind pump, Ukunda (Pwani)
5. District water supply — Wind pump, Kilifi (Pwani)
6. School water supply — Wind pump, Baragoi Sec. Sch. (Kijito)
7. Turkana Rehabilitation Project — Wind pump, Kaikor (Kijito)
8. Irrigation, Wind pump, Garissa (Pwani)
9. Electric supply — Wind generator, Olosseos Health Centre
10. Domestic electric supply — Wind generator, Mbooni



Starting a Project 8

The previous chapters describe renewable energy systems found in Kenya. Their focus is mostly on the many *successful* projects countrywide. Much can be learned by visiting a project that is working well, be it a biogas digester, a windpump, a fodder and woodfuel producing dairy scheme or an improved *jiko* workshop.

However, for every successful renewable energy project, there are failures, and in many places renewable energy devices sit unused and rusting. There are examples of failed biogas digesters, mud stoves, solar water pumps, and windmills all over the country. Even large, expensive projects, on which millions of shillings were spent, have failed because of simple mistakes made during planning stages or because of lack of proper follow-up care. We can learn from our own mistakes, but is much *cheaper* to learn from the mistakes of others.

This final chapter is a guide for those who want to plan or build their own renewable energy projects. No matter how small or large an energy project is, it must always be *well planned* so that the energy needs are met by well-designed, cost-effective solutions which can be powered and maintained locally.

During the planning stages of an energy project, the total energy needs should be estimated, and the possible solutions assessed and compared. A visit to a similar project is highly recommended before starting one's own project. The six stages listed below will assist in planning a renewable energy system:

1. Estimate the amount and form of the priority energy need.

2. Assess the energy, raw material and financial resources available.

3. Find out which energy systems and devices are available and which needs they can supply.

4. Decide which system is the most worthwhile for the situation.

5. Visit a working example of the chosen energy system.

6. Decide who will build, install, operate and maintain the system.

Energy Requirements

The chapter on "Energy and Development" discusses the energy needs of rural Kenya. These include energy for cooking, water supply, lighting, space and water heating, as well as for running appliances and machinery. Because different renewable energy systems supply different forms of energy, one must first decide which energy need is the most important. Cooking requires heat energy supplied by wood, charcoal or biogas, whereas running a television requires energy in the form of electricity.

For example, in the case of a boarding school, the supply of energy for cooking and procuring clean water might be considered more important than supplying energy for lighting the classrooms. But if there is a clean permanent stream less than 100 yards from the compound, and if firewood is plentiful and cheap, the school might first want to concentrate on meeting its lighting energy needs.

Farmers in woodfuel shortage areas should also have priorities in meeting their energy needs. If women spend much time and/or money in their search for fuelwood, then the cooking energy problem should be given high priority. An improved stove or a woodfuel production system should probably be started before a solar cell module is bought to power the cassette player.

There are several factors involved in deciding which energy needs are the most urgent. The two most important are *costs* of fuel and *time* spent collecting fuel. By *measuring* the amount of fuel (i.e. paraffin or charcoal) used in a month, one can find the sum total of money spent on the fuels in the month. By measuring the amount of fuelwood or water used in a month, one can estimate the amount of time spent fetching firewood or water per month. This information helps one make economic comparisons between energy devices. (see pages 143, 146).

The form in which energy comes helps to determine the *needs* to which the energy can be applied and the *cost* of the energy. For example, the chemical energy stored in wood is cheaply available, but its applications are limited. Woodfuel energy can be directly used for cooking and space heating but it cannot be used for powering a radio (unless it is used as a fuel for a generator). Paraffin is more expensive than wood,

but it can be used for both cooking and lighting. Biogas, more expensive yet, can be used for cooking, lighting or for running engines. Electricity is the most versatile form of energy, with the capacity to power lights, cassette players, small machines, cookers and water heaters, but it has to be generated from other energy forms.

Calorific fuels (wood, charcoal, biogas) produce heat and thus supply most of the energy in rural areas. As much as 99% of the energy used in a community is for such thermal applications as cooking, space heating and drying.

Mechanical and electrical forms of energy, on the other hand, supply a very small fraction of any rural community's total energy demand. However, this energy, supplied by the grid, wind power, solar electricity, small-scale hydropower or stationary diesel engines, meets important needs. Lighting, water pumps, posho mills and such appliances as lathes, sewing machines and radios consume small amounts of energy, but the services they provide are important to the community.

A final aspect of community energy needs are variations in the demand. This is the change in amounts of energy needed over time. Is energy for a given job needed *continually*, as with a refrigerator, at *night only*, as with lights, or only *intermittently* as with hot water? Is it *seasonal*, as with a posho mill, irrigation pump or tractor, or is it *daily*, but at changing intervals, as with a sewing machine or workshop lathe?

Assessing Energy, Raw Materials and Financial Resources

In order to use a renewable energy to meet a quantified need, the resources available that can help meet that need must first be measured. Obviously, a person living in a riverless semi-arid area cannot choose water power, and a person in a windless area cannot use windpower to meet his water pumping needs. Likewise, a farmer on a quarter acre of land cannot turn his entire *shamba* into a woodlot to meet his woodfuel and wood product requirements. It should also be noted that a person without money cannot buy the parts for a biogas digester.

Anyone wishing to start a project should add up the amount of financial and material resources he has available to spend on the project. The amount of money, livestock, materials and land at one's disposal will limit the size of the project undertaken. Some renewable energy systems, such as wind pumps and biogas digesters require a lot of money. On the other hand, such projects as energy conserving stoves and hedgerow cropping require almost no money. Once the financial and material resources available have been determined, one will have a realistic idea of what renewable energy can be afforded.

Total renewable energy resources should be measured next. What are the monthly sunshine variations? How much water power is there on a

Handpumps are effective water supply tools as they use human power, are locally made and easily maintained.

continual basis? What are the biomass resources on the *shamba* (trees, agricultural wastes, animal wastes). Site surveys which include seasonal variations in each renewable energy should be made following the outlines under the respective chapter headings (wind, hydro, solar, etc.). Accurate estimates of each local renewable energy will provide the basis for any decision to use renewable energies.

When considering the energy resources available, commercial energy should also be included. Easy access to grid electricity, paraffin and other petroleum fuels may make commercial energy (such as grid power or stationery generators) attractive solutions. Long distances to fuel pumps, frequent shortages or power outages may make them unattractive.

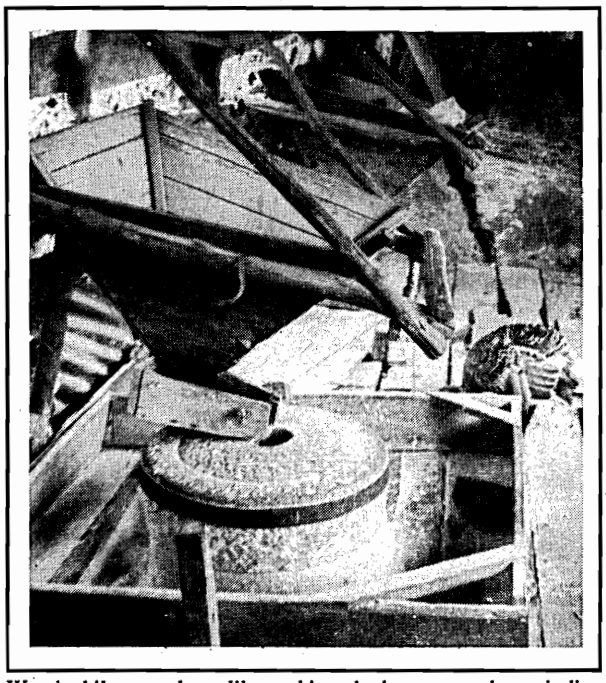
Energy Systems Available and Needs they Supply

A person's access to any technology is limited by the information available, by how far the person can go in search of the technology and by which technologies are located in the immediate community. This book describes many renewable energy systems that are available in Kenya. The appendix that follows this chapter lists some of the local organisations involved in renewable energies and their addresses. The better knowledge one has of what energy solutions are available, the wider range of choices one will have when actually choosing to use (or *not to use*) an energy system.

Additionally, the better knowledge one has of what each renewable energy can do, the better equipped he will be to make a final choice. For example, solar electricity cannot cheaply provide thermal energy. One cow will not provide enough wastes to produce biogas for a family's cooking needs. A pelton wheel requires at least 10-15 metres of head in order to work properly.

Some renewable energy devices (i.e. microhydro generators, solar cookers, etc) have promise in Kenya

but are not yet being locally manufactured. Individuals interested in these technologies will have to find information about these devices and pioneer the field themselves. Assistance from organisations such as Kenyatta University Appropriate Technology Centre (and other organisations listed in the appendix) should be sought in the way of technical and design information.



Worthwhile tools, like this hydro-powered grinding stone, use energy sources that are readily available .

Which Solutions are the Most Worthwhile

Sooner or later, one must actually decide how he is going to meet his energy need. Any decision should be made by carefully weighing the benefits and disadvantages of each solution.

Which solution is the most adaptable? There may be one important energy requirement that needs to be solved, or there may be several. If there are several energy needs then an adaptable form of energy might be the most practical. For example, solar water heaters only can produce hot water, while fuelwood can cook food, heat water, and heat the house during cold weather (and also provide construction materials). If hot water is the only priority need (i.e. in a hospital whose electrical and cooking needs are already met), then solar water heaters might be the best energy solution. But if there are other priority needs, money and resources could be better spent on a more versatile energy form.

The manpower (or womanpower) necessary to operate, maintain and repair a renewable energy system should be considered. Does the device require that someone be hired to operate it? Biogas digesters must be fed on a regular basis. Wind pumps must have their bearings greased every three months. Agroforestry systems must be weeded. Devices such as hydraulic rams and solar collectors, on the other hand, need little attention.

Chances are, spare parts for any device will eventually be needed. Many imported windpumps break down and cannot be repaired because a relatively cheap spare part is not available. The more remote an installation site, the more difficult it will be to get spare parts. Always inquire with manufacturers of R.E. devices about the availability of spare parts.

In almost every case, the most *worthwhile solution* is the most *economical one.* Making a complete economic assessment of all the benefits of a project is quite complicated. However, a financial comparison of various solutions can be made by examining the costs of each solution over its lifetime. These costs include:

The first cost of the device: The amount of money spent to buy, transport and install the device.

The annual recurrent costs: How much must be spent to operate, provide fuel for, maintain and repair the device per year.

The investment costs: How much interest must be repaid for any loans taken out to buy the device.

For small devices, it is quite easy to make economic assessments of the possible solutions. For example, although the Kenya Ceramic Jiko is more expensive than the traditional metal *jiko,* it is clearly more economical for it uses up to 50% less charcoal and will recover the cost difference within 1-2 months. Hydraulic rams can also be economically justified quite easily because their *first cost* is less than the diesel pump that would otherwise be needed and they have no *recurrent costs* (as do diesel pumps).

On the other hand, larger projects such as biogas digesters, windpumps, wind generators, solar electric systems and microhydro generators require careful economic assessment. All of the financial variables should be added up and considered. It is a good idea to seek the advice of a skilled financial assessor when deciding on a very large project.

At this stage, the choice of solutions for energy needs should be narrowed down to the most realistic ones. Maybe two or more renewable energy systems combined can meet priority energy needs. For example, on a small farm, agroforestry systems can be used for wood production, a *Maendeleo* stove can be used to conserve woodfuel and a small 10 watt solar cell module can be used to supply electricity for lighting and powering the radio. The next step, visiting other projects, helps in examining the perceived most realistic and worthwhile solution.

Visiting a Working Project

Before spending time and money to build and/or buy a renewable energy system, one should be convinced that the chosen solution will actually work in one's own situation. One reads about various renewable energies in newspapers and books, hears about them

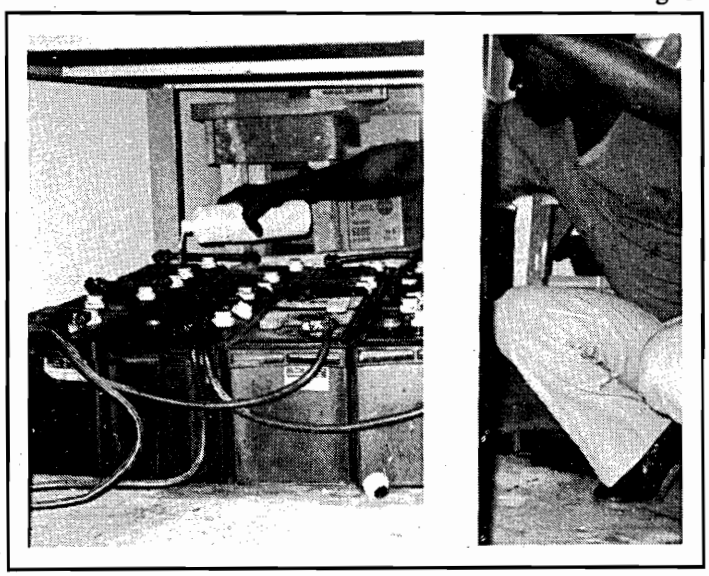
through word of mouth or over the radio or even sees them on television, but nothing takes the place of actually *visiting* a working project. In Kenya, there are good opportunities to visit projects in many parts of the country.

The more expensive a given renewable energy system is, the more important it is that the prospective buyer or builder sees a working example. On a visit, one can answer one's own questions about the technology, find out what is involved in construction, operation, maintenance and repair, and discover advantages and disadvantages of the system of which one was unaware. Furthermore, one can often find assistance for designing and constructing his own project during a visit.

Below are useful questions that can be asked during a visit. It is helpful beforehand to write down a list of questions to ask the project manager and to carry a notebook and pen to jot down information.

1. What energy needs does the system supply?
2. What are the necessary inputs (labour, fuel, etc.)?
3. How much did it cost?
4. How long has it been working?
5. How easy is it to operate?
6. Who built and designed it?
7. Are the site conditions similar to one's own site conditions?
8. Is it working as described?
9. Do all of the appliances (cookers, lights, pumps etc.) work?
10. Can improvements be made in the design?
11. Has it ever broken down?

Finally, when visiting a project, it is a good idea to bring the person who will actually operate one's own project along. That person can see how work is done and talk with the project operator on site. In the case of an improved stove, a cook can learn how to use the improved stove by seeing another one in use. Or, in the case of a windpump, a maintenance worker could actually help the operator grease the machine, thus getting a head start on maintenance skills.



Project maintenance is essential. Wind generator batteries are topped with distilled water (left).

Project Personnel

Once one is sure that a particular renewable energy system will meet one's needs, and that he has the necessary material and financial resources to support its building, one must decide who will build, operate, maintain and install the system. Many renewable energy project failures can be attributed to lack of qualified builders or maintenance personnel.

Building and Installing

Building and installing a system by oneself may often be the best solution. It is definitely the cheapest, and when one does install a system, one gains complete knowledge of how the system works, and how to maintain and repair it. For example, with a little knowledge of electric principles, one can install a solar electric system in one's own house. Likewise, with design assistance from an agroforestry centre, one can start a hedgerow cropping system on one's farm. But building a device such as a windpump is very difficult without a well-equipped machine shop, tools and the skills necessary to use the tools.

The advantage of hiring qualified people to build and install renewable energy systems is that they have skills and experience. A group of biogas constructors might have already built many digesters and therefore grown familiar with construction methods. Mud stove builders with experience are less likely to build stoves that crack within a few weeks. The more unfamiliar with a technology one is, and the more complicated the technology, the more important it is to seek experienced assistance.

One can assess the work of the person or company who is to build or install his system during a project visit and talk with the owner of a previous project to find out if he is happy with the way the individual or company built it.

Operation and Maintenance

This part of the project planning is often ignored, and a great many projects fail because of poor operation and maintenance. Renewable energy systems are not magic. They are apt to break down or to stop producing usable products, just like motor vehicles, if they are not cared for. Therefore someone must be trained and responsible for project operation.

Improved stoves, especially those used in institutions, must be operated properly if they are to save wood. Therefore, the cook(s) must be shown how to use them. Biogas digesters must be stirred, fed and repainted on a regular basis, and someone must be employed to do this work. Every renewable energy system and device needs some type of maintenance. The project administrator must thus plan ahead to make sure that this work will be done by *someone*.

Starting a Project: A Local Example

Below, an actual successfully planned biogas digester installation is described. The digester was still working at a farm near Chuka at the time of this book's publication. This example is meant to illustrate the *planning* stages of any renewable system.

Which Energy Needs Must be Met First

Mr. Mugo runs a small business in Chuka and owns a farm outside of town where he lives. He and his wife grow tea, coffee and bananas as cash crops, and maize, beans, fruits and vegetables for their own consumption. Mrs. Mugo cooks for her family of eight members with firewood. She spends as much as four hours per week cutting and collecting branches, and uses about 20 kg of wood per day cooking and heating water over a three stone fire.

At night, the family uses paraffin lamps (a pressure lamp and several wick-type lamps) for reading, knitting and studying. The lamps consume about four litres of paraffin per month to provide lighting.

Mrs. Mugo and her two daughters used to have to travel to a small stream (about 500 m away) at the edge of their property to fetch water. However, now that the family has built a 10,000 litre storage tank which collects rainwater from the roof, they only have to fetch water during the last weeks of the dry season.

Mr. Mugo's son, Murithii, a secondary school teacher, buys as many as 12-14 dry cell batteries per month to power the family's torches and radio/cassette player. Sometimes, batteries are scarce. Mr. Mugo does not have a refrigerator or any other machines, nor does he hope to buy any in the near future.

Mrs. Mugo, her house-help and her children do most of the work on the *shamba*. Because their plot is located on a steep hillside and produces many different crops, they do not use any machines on the farm. All work is done by hand using *pangas* and *jembes*. They used to buy several bags of commercial fertiliser per season to apply to their maize, coffee and banana plants along with the manure from their five head of cattle. After harvesting, Mrs. Mugo takes some of the maize crop to a local *posho* mill for grinding.

The family decided that the two most important energy problems which needed to be solved were providing energy for cooking and energy for lighting.

Assessing Energy, Material and Financial Resources Available

Energy Resources. Fuelwood is available from trees on the farm, but it is a lot of work for Mrs. Mugo to constantly prune branches from trees, especially since all of the children attend school or do not live at home. She needs to devote most of her time to running the coffee, tea and maize *shamba*.

The farm's five grade cattle (and one calf) are not kept in a zero-grazing enclosure. They graze in a small pasture on the hillside and are kept in a *boma* at night. Much of the animals' waste accumulates in the *boma* which is quite near the house.

Solar energy is a plentiful resource, and Mrs. Mugo already uses solar energy to dry harvested beans and maize. However, between the months of May and August it is usually quite cloudy. There is little wind in the Chuka area and the nearby stream does not have enough head or flow to be considered useful for providing energy.

Commercial sources of energy are available around Chuka. The grid lines are located about two kilometres from Mr. Mugo's house. LPG gas can be bought in Chuka or Embu but is often in short supply. Paraffin, petrol and diesel fuels are available from three petrol stations in Chuka.

Financial and Material Resources. Mr. Mugo had been saving money from his business in order to make improvements on his farm, and his son had also agreed to contribute money toward any project that they agreed on. Together, they were able to raise a maximum of about KShs10,000. Mr. Mugo could also have borrowed money from an agricultural cooperative.

There were a few building materials around the farm. They included stones, ballast and sand left over from building the water tanks. There was plenty of timber, some bags of cement and some PVC pipe fittings.

Which Energy Systems and Devices are Available?

Murithii read about and met with some people who knew about renewable energy systems. Then he discussed his ideas with his parents and they came up with a list of possible solutions to their cooking and lighting energy needs. The table below summarises the ideas they discussed.

Table 8.1: Energy Systems and Devices Available

SYSTEM OR DEVICE	ENERGY FORM	USES	FIRST COST*/ ANNUAL RECURRENT COST
Solar electric system	Electricity	Lighting, radiocassette	High/low
Liquid petroleum gas (LPG)	Chemical (Gas)	Cooking, lighting	Medium/medium
Mains power	Electricity	Lighting, radiocassette cooking, appliances	High/medium
Improved wood stove	Chemical (Wood)	Cooking	Low/none
Biogas digester	Chemical (Gas)	Cooking, lighting	High/low

*Costs (1986 Ksh) High: 8,000 Ksh. or more; Medium: 2,000 - 7,999 Ksh.; Low: below 2,000 Ksh.

Which Solution is Most Worthwhile?

Murithii was first very interested in solar electricity, but later found that solar cell modules could not cheaply supply electricity for cooking. Mrs. Mugo thought LPG gas was a good idea because it could be used for both cooking and lighting and it was very easy to operate.

Mr. Mugo had suggested mains electricity, which some people in the area have installed in their houses. However, when he visited a friend who used mains electricity, he found the family cooking with wood. Using electricity for cooking, they said, greatly raises the electricity bill. Mrs. Mugo was not in favour of using an improved stove because she did not think it would reduce her wood-gathering chores. Nor would it solve the lighting problem.

Finally, Murithii also suggested a biogas digester, which he had read about in the newspaper and talked about with other teachers. He had heard that the wastes from four cattle could produce enough gas for a family's cooking and lighting needs. He decided to find out more information about biogas and started reading a book about biogas borrowed from a friend.

The family narrowed their final choices down to LPG gas cylinders (which Mrs. Mugo was highly in favour of) and a biogas digester (which Murithii was arguing for). Solar electric devices produced too little energy for cooking. Mains power was too expensive for cooking uses. An improved stove was not versitile enough to provide energy for lighting.

The family then compared the two energy types carefully. Biogas and LPG are both adaptable for lighting and cooking. Both require appliances such as cookers and lamps that can use the gas. LPG gas cylinders must be refilled when they get empty. Biogas digesters, on the other hand, must be continually maintained. Mrs. Mugo, who knew that she would be operating the digester, was wondering exactly how much work it would require.

From the Ministry of Energy and Regional Development, Murithii got information about the cost and materials needed to build a digester. He decided to compare the total cost of a biogas digester with that of an LPG gas system. The total *cost* of each system over its *lifetime* is the *first cost* plus the *recurrent costs* plus the *investment costs*. He calculated the first cost of both systems as described in the table that follows:

Table 8.2: First cost† of 9.4m³ biogas digester vs LPG gas system

BIOGAS SYSTEM		LIQUID PETROLEUM GAS	
Appliances		**Appliances**	
Double Gas Cookers*	KShs 750	Double Gas Cooker*	KShs 750
Two lamps*	KShs 1100	Two lamps*	KShs 1100
Biogas Digester			
Construction materials (cement, sand, ballast, stones)	KShs 1000	Gas Cylinder	KShs 600
Fittings, pipes values	KShs 1200		
Labour	KShs 2500		
Gas collector & transport	Kshs 3300		
Total First Cost	**KShs 9650**		**KShs 2450**

† 1986 prices

*Biogas appliances made by Kenya Industrial Estates.

Notice that the cost of biogas construction materials was only KShs 1000 because Mugo already had cement, stones, ballast, sand and some pipes. A 9.4m³ Sasse biogas digester actually costs between KShs11,000 and KShs.14,000.

Next, he calculated the *annual recurrent costs* of each system (how much money is spent per year on fuel and maintenance, see table below). The lifetime of a biogas digester is estimated to be about 15 years or longer. The annual recurrent cost of each system is thus multiplied by 15 years to get the lifetime recurrent costs.

Table 8.3: Lifetime Recurrent Costs: Digester vs. LPG System

BIOGAS DIGESTER		LIQUID PETROLEUM GAS	
Annual maintenance	Ksh 200	Cylinder refills (12-16 per year)	KShs1500-2000
x 15 years		x 15 years	
Lifetime Recurrent Cost	**KShs 3000**		**KShs 22500**

Murithii used the figure of 12 cylinders of gas per year as an estimate for LPG gas consumption even though many families use more than 12 cylinders per year. However, the lifetime recurrent costs clearly indicated that LPG systems are expensive. The total lifetime cost of each system is calculated in Table 8.4.

The *investment costs* are also supposed to be calculated into the lifetime cost calculations. However, because it was not necessary for Mr. Mugo to take out a loan in this case, Murithii did not have to calculate any investment costs.

Table 8.4: Total Lifetime Costs: Biogas and LPG System (15 Years)

	BIOGAS DIGESTER	LIQUID PETROLEUM GAS
First Cost	KShs 9,650	KShs 2,450
Recurrent Cost	KShs 3,000	KShs 22,500
Investment Cost	-	-
Total Lifetime Costs	**KShs 12,650**	**KShs 24,950**

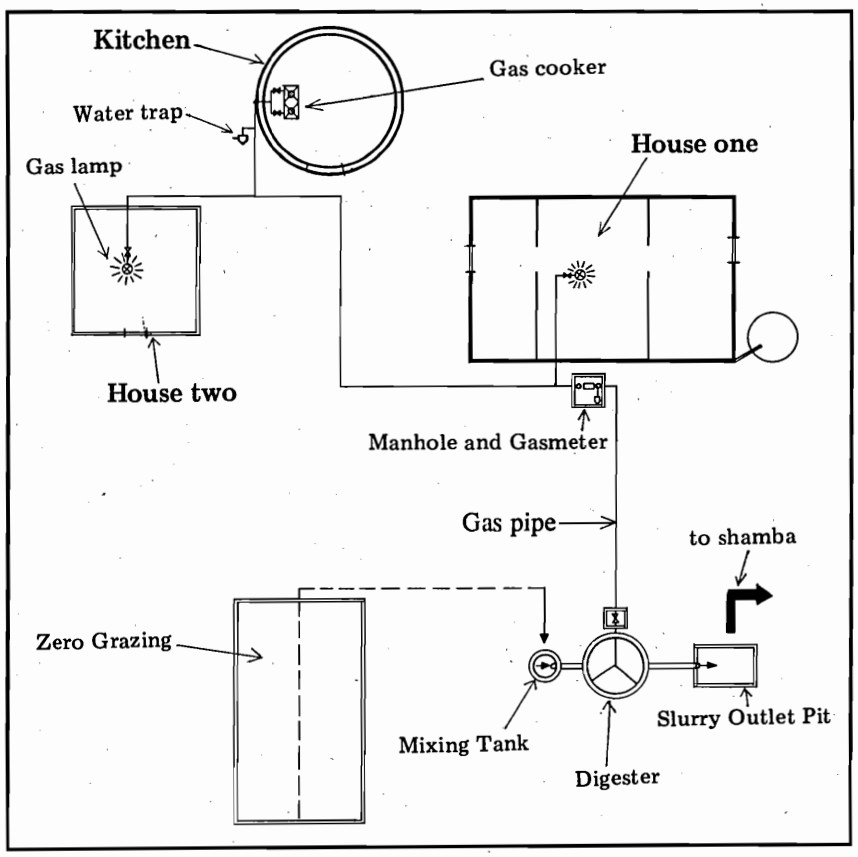
Murithii found that because the recurrent costs of a biogas digester are low, its total lifetime cost is much lower than that of the LPG system. LPG cookers and lamps require that fuel be bought on a regular basis and over the years these costs add up.

Murithii pointed out two other important questions that could not easily be included in the financial comparison. First, he asked, *"What about when the price of LPG goes up?"*. Secondly, he asked *"What if gas cylinders become scarce?"*. Not all questions can be included in a financial comparison because of future uncertainties.

After he was convinced that a biogas digester was ideal for his family's situation, Murithii met with a biogas builder named Mbaka who convinced him to visit a biogas digester that he had helped build.

Visiting a Working Biogas Digester

Murithii, Mbaka and Mr. and Mrs. Mugo travelled to Mitunguu, Meru, to visit a 9.5 m^3 Sasse digester located on the *shamba* of the Kinoti family. During the visit the Mugo family was very impressed by the digester, and they learned much that they did not know. When they arrived, Mrs. Kinoti was cooking lunch on the biogas cooker and in the kitchen, Mrs. Mugo discussed the digester with her. Meanwhile, Mr. Kinoti showed Mr. Mugo and Murithii the digester which Mbaka had helped build.

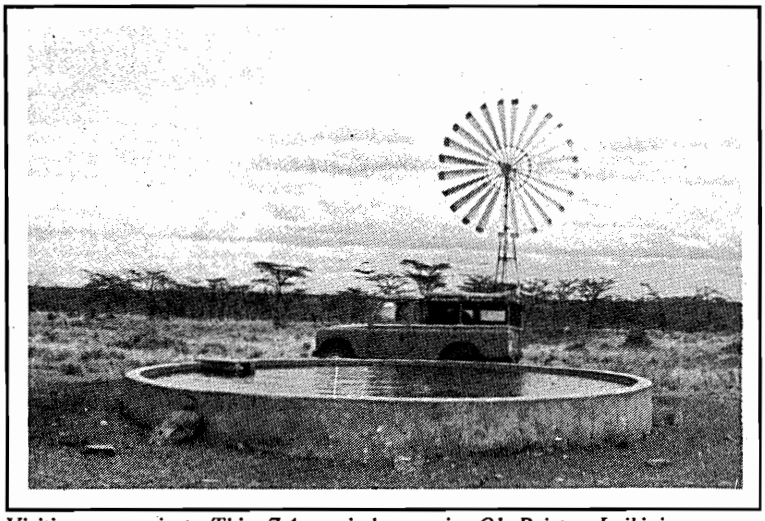


It is often a good idea to draw a project plan. The biogas layout above is for a digester in Khwiseru, Kakamega district.

The Kinotis keep four cattle in a zero-grazing enclosure. All of the cattle wastes are washed from the floor of the enclosure directly into the digester. The system supplies enough gas to cook all of the family's meals and to light several rooms for 3 or 4 hours a night. Mr. Kinoti said that the system was paid for mostly by a German grant in 1983.

After lunch, Mrs. Kinoti demonstrated how she operated the digester, mixing cow wastes with water, pouring them through the inlet, and then stirring it with a long stick. She said that the digester had never broken down, but that during the dry season when their water tank was empty they had trouble getting enough water to feed it (a digester requires an equal volume of cow dung and water everyday).

Mrs. Kinoti told them that she was most pleased with the biogas *effluent*, which is a very good fertiliser. After applying it to her maize fields and fruit trees for several seasons she has noticed that



Visiting a project. This 7.4m windpump in Ol Pejeta, Laikipia, pumps water for livestock.

yields have increased. Mrs. Kinoti pointed out that they no longer bought commercial fertiliser because the effluent works as well or better than the commercial type.

The Mugos noticed that the climate at the Kinotis was not the same as the climate at their *shamba*. The Mugos farm is in a coffee and tea growing area, while the Kinotis live in an area just below the coffee belt where the main cash crop is tobacco. Mrs. Kinoti informed them that less gas tends to be produced in cooler climates, but that she knew of a digester in a tea-growing area near Meru town which works well.

Mr. Mugo asked Mr. Kinoti which part of the biogas system he was least happy with. He said that although the gas lamps gave out a good light, their mantles did not last very long. He thought that the lamps could be made in a better way. Finally, Mr. Mugo asked Mr. Kinoti if he thought Mbaka was qualified to build a digester at the Mugo *shamba*. Mr. Kinoti said yes, but that Mbaka might need some help with the masonery work.

Based on the knowledge they gained from the visit, the Mugos were able to make a decision. Whereas Mrs. Mugo was skeptical *before* seeing a digester, her visit with Mrs. Kinoti convinced her that biogas was a practical technology.

Deciding on Project Personnel

The Mugo family decided to build a Sasse 9.4m^3 digester. They hired Mbaka, his assistants and a mason to construct the digester near their cattle *boma*. It took them about two weeks to finish the construction, and another week to fill the digester with slurry.

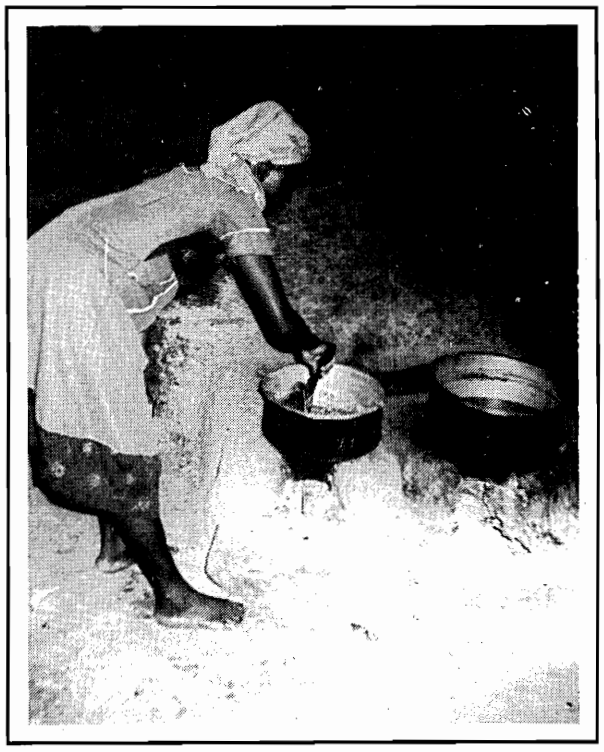
The gas collector, lamps and cooker were built and bought in Nairobi. Mrs. Mugo got the job of operating the digester. She found the work to be less than collecting firewood. Once it started producing gas, Mrs. Mugo was able to do most of her cooking chores with biogas. The gas lamps provided light in the kitchen and sitting room.

In its first year of operation, the digester did not experience any major problem. When a gas pipe had a leak, they called Mbaka (who lives a few kilometres away) to repair it. Mbaka passes by the *shamba* occasionally to make sure they are maintaining the digester and to see if they have experienced problems. Although there are times when the methane output of the digester does not meet all of the cooking fuel needs, the fertiliser value of the slurry has proven to be effective in supplying nutrients for the coffee, banana and maize crops on the farm. The digester has been a success for all parties involved.

Conclusion

The above example is not the only way the Mugo family could have solved their energy problems. However, they did carefully consider their requirements and they did try to find the best solution possible. Furthermore, they visited a working project to assure themselves that the solution they had agreed upon was the best. Now several other people who live near Mr. and Mrs. Mugo have visited their digester and built biogas digesters on their own farms.

This book is meant to supply information about renewable energies in Kenya, and to direct people to sources of information and expertise. Hopefully, with the basic knowledge contained herein and the resources contained in the appendix that follows this chapter, readers will be able to evaluate their own needs, and, like the Mugos, go out and visit working projects before embarking on their own. *Mafanikio mema!*



Using a Maendeleo II stove, Chuka, Meru.

Appendix

Organisations Producing and Disseminating Renewable Energies in Kenya

Below is a list of organisations involved in various renewable energy fields as of 1987. Though incomplete, it is intended to serve as a guide for those interested in finding more information about renewable energies. The first section catalogues organisations working in more than one RE field, and the sections that follow list organisations according to the type of renewable energy with which they are involved: wood, non-wood biomass, solar, hydro, and wind.

A. Organisations Working with Several Renewable Energies

1.	Ministry of Energy and Regional Development: Kenya Renewable Energy Development Project (KREDP)	UTALII HOUSE 8TH FLOOR P.O. Box 30582 NAIROBI Tel: 340800	Agroforestry Biogas Improved Stoves and Kilns Solar Energy Wind Energy Library: Gen. Information

KREDP AGROFORESTRY/ENERGY CENTRES:

a. Mtwapa (Coast)	P.O. Box 90290 MOMBASA Tel: 485237	Agroforestry Biogas Improved Stoves and Kilns
b. Wambugu (Central Highlands)	P.O. Box 5069 NYERI Tel: 4531	Agroforestry Biogas Improved Stoves and Kilns
c. Bukura (Western)	P.O. Box 92 BUKURA Tel: 23 BUTERE	Agroforestry Biogas Improved Stoves and Kilns
d. Kisii (Lake Basin)	P.O. Box 52 KISII Tel: 20586	Agroforestry Biogas Improved Stoves and Kilns
e. Jamhuri (Uplands)	P.O. Box 21552 NAIROBI Tel: 565232	Agroforestry Biogas Improved Stoves and Kilns
f. Kitui (ASAL)	P.O. Box 737 KITUI Tel: 112	Agroforestry Biogas Improved Stoves and Kilns

2.	Egerton Agricultural College	Private Bag, NJORO NAKURU Tel: 40861	Agroforestry Biogas Improved Stoves Solar Water Heaters and Driers
3.	GTZ/Special Energy Programme	P.O. Box 41607 NAIROBI Tel: 722853	Agroforestry Biogas Improved Stoves and Kilns Solar Water Heaters Handpumps Wind Energy

4.	Karen Village Technology Unit	P.O. Box 302760 NAIROBI	Biogas Biomass Stoves Handpumps Hydrorams Improved Stoves Solar Cookers, Driers and Water Heaters
5.	Kenya Energy Non-Government Organisations Association (KENGO)	P.O. Box 48197 NAIROBI Tel: 749747	Agroforestry (seed supply) Biogas Improved Stoves and Kilns General RE Information Library
6.	Kenya Industrial Estates (KIE)	P.O. Box 30650 NAIROBI Tel: 542300	Biogas Appliances Windpumps and Generators Handpumps Solar Water Heaters Library
7.	Kenyatta Appropriate Technology Centre (KATC)	P.O. Box 43844 NAIROBI Tel: Kahawa 356 Ext 342	Improved Stove Testing Solar Driers, Stills, Cookers and Water Heaters General RE Information Library
8.	Murang'a College of Technology	P.O. Box 75 MURANG'A Tel: 22906	Institutional Stoves Hydrorams Biogas

B. Trees for Energy - Agroforestry/Woodfuel Production

9.	CARE-Kenya	P.O. Box 43864 NAIROBI Tel: 724674	Agroforestry Woodfuel Conservation
10.	International Council for Research in Agroforestry (ICRAF)	P.O. Box 30677 NAIROBI Tel: 29867 & 332304	Agroforestry
11.	Kenya Woodfuel Development Project (KWDP)	P.O. Box 56212 NAIROBI Tel: 582916	Agroforestry Woodfuel Production Tree Seed Supply
12.	Ministry of Agriculture Soil Conservation Project	P.O. Box 30028 NAIROBI Tel: 721689	Afforestation Soil Conservation
13.	Permanent Presidential Commission on Soil Conservation and Afforestation	P.O. Box 30510 NAIROBI Tel: 21034	Afforestation Soil Conservation
14.	Rural Afforestation Extension Scheme (RAES), Kenya Forest Department	P.O. Box 30513 NAIROBI Tel: 722620	Afforestation Nursery Management

See also: KREDP Agroforestry Centres, KENGO

-Woodfuel Conservation: Improved Stoves and Kilns

15.	Action-Aid	P.O. Box 42814 NAIROBI Tel: 62761	Institutional/Improved Stoves

16.	Bellerive Foundation	FUEL SAVING PROJECT: RUIRU P.O. Box 21734 RUIRU Tel: 569705	Institutional/Improved Stoves
17.	Clayworks Ltd.	THIKA ROAD P.O. Box 48202 NAIROBI Tel: 802266	Ceramic Liners for Kenya Ceramic *Jiko* and *Maendeleo* Stoves, Bricks for Kilns
18.	East African Tannin Extract Co., Ltd.	P.O. Box 190 ELDORET Tel: 31311	Beehive Brick Kilns
19.	Burns and Blane, Ltd.	KAMPALA ROAD P.O. Box 45860 NAIROBI Tel: 542043	Mark V Portable Kilns Alfa Laval Stoves
20.	Ital Products, Ltd.	OL KALOU ROAD P.O. Box 48952 NAIROBI Tel: 556950	Institutional Stoves
21.	Jerry International	P.O. Box 52747 NAIROBI	Ceramic Stove Liners
22.	Kenya Planter's Cooperative Union Ltd. (KPCU)	DANDORA STORE KOMO ROCK RD. P.O. Box 72309 NAIROBI Tel: 28761	Coffee Husk Charcoal
23.	Maendeleo ya Wanawake	P.O. Box 41607 NAIROBI Tel: 722853	*Maendeleo* Stoves Tree Planting
24.	Prisons Department	P.O. Box 30175 NAIROBI	Improved Stoves Sawdust Stoves
25.	UNICEF	P.O. Box 44145 Tel: 333930 Ext 2040	Improved Stoves

See also: MOERD Improved Stove Section, KENGO

C. Non-Wood Biomass

26.	Apro Energy Enterprises	Bamburi Rd. P.O. Box 11927 NAIROBI Tel: 552905	Wonder Stove Biomass-powered Water Heaters
27.	Biogas Section, MOERD	UTALII HOUSE, 8TH FLOOR P.O. Box 30582 Tel: 340800	Biogas Digesters: Designs, and Technical Advice
28.	General System, Ltd.	P.O. Box 78181 NAIROBI	Amica Gasifiers
29.	Tunnel Engineering, Ltd.	P.O. Box 1 KORU Tel: 14, 15	Biogas Digesters Solar Water Heaters

D. Solar Energy Systems

30.	Alpa Nguvu	P.O. Box 45155 NAIROBI Tel: 746290	Solar Electric Systems Solar Water Heaters
31.	Animatics	P.O. Box 72011 NAIROBI Tel: 557041	Solar Electric Systems - Refrigeration, Fencing Pumps, Home Systems

32.	Chintu Engineering Works Ltd.	SARIT CENTRE P.O. Box 11467 NAIROBI Tel. 747407	Solar Electric Components and Accessories
33.	Chloride Exide Kenya Ltd.	P.O. Box 14242 NAIROBI Tel. 554773	Solar Batteries Solar Electric Systems Security Systems
34.	Kensid	P.O. Box 18511 NAIROBI Tel: 555622	Solar Electric Systems
35.	Securicor Solar Services	P.O. Box 30242 NAIROBI Tel: 559070/62	Solar Electric Systems - Home Systems - Refrigeration - Security Systems
36.	Solar Shamba	P.O. Box 894 EMBU Tel: (0161) 20554	Solar Electric Systems: Installation and Design
37.	Solar World	KISII	Solar Electric Systems Solar Water Heaters
38.	Total Solar	P.O. Box 18465 NAIROBI Tel: 555520	Solar Water Heating Solar Electric Systems

See also: Tunnel Engineering, Kenya Industrial Estates, Kenyatta Appropriate Technology Centre, Sound Communications.

E. Small-Scale Hydropower Systems

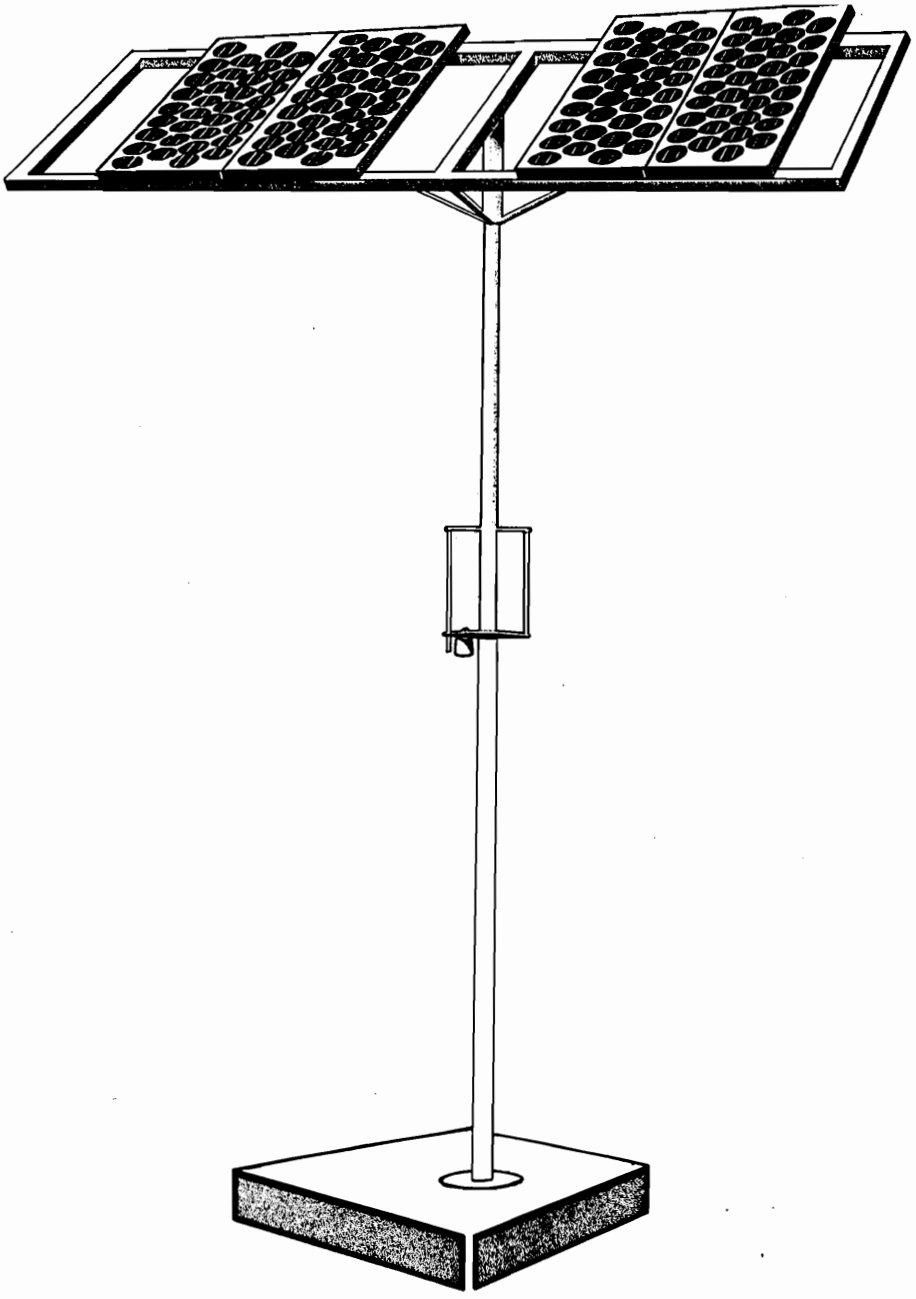
39.	Machinery/Services Ltd.	WITU ROAD P.O. Box 30342 NAIROBI Tel: 557844	Blake Hydraulic Rams
40.	Ndume, Ltd.	P.O. Box 62 GILGIL Tel: (03671) 2121	Hydrorams, Waterwheels, Handpumps, Turbopump
41.	WECO	P.O. Box 190 KAKAMEGA	Hydrorams, Handpumps
42.	Wigglesworth	KAMPALA ROAD P.O. Box 30092 NAIROBI Tel: 557022	Hydrorams

See also: Murang'a College of Technology

F. Wind Power Systems

43.	Bobs Harries Engineering, Ltd.	P.O. Box 40 THIKA Tel: Thika 47234	Windpumps
44.	Pwani Fabricators	P.O. Box 83381 MOMBASA Tel: 24991	Windpumps
45.	Sound Communications	P.O. Box 18286 NAIROBI Tel: 556177	Wind Generators Solar Electric Systems

Woodfuel, hydro and solar energy resources already meet major energy needs in Kenya. However there is a potential for these and other renewable energies to be used on an even wider scale. This book describes the principles and useful applications of renewable energy systems now working in Kenya. Furthermore, it refers readers to successful local projects which can be visited for first hand experience

The author, Mark Hankins, was a science teacher in Kenya from 1983 to 1986. His work included training youths in the design and installation of small biogas, solar electric and agroforestry systems.

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