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COMPETE

Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems - Africa

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Traditional, improved and modern bioenergy systems for semi-arid and arid Africa

Experiences from the COMPETE Network

DRAFT

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1 Introduction

Current global energy supplies are dominated by fossil fuels of about 500 EJ per year, while biomass provides about 50 EJ, making it by far the most important renewable energy source used. *(IEA, 2008)* A major part of this biomass (70-80%) is used for traditional non-commercial use mainly in developing countries. Energy demand in Africa is much lower with only about 5.2% of global energy demands and a share of 3.1% of global electricity generation. (IEA 2008)

Biomass energy plays a vital role in meeting local energy demand in many regions of the developing world. Biomass is a primary source of energy for close to 2.4 billion people in developing countries (IEA, 1998). The heavy reliance on biomass is notably prominent in sub-Saharan Africa, where biomass accounts for 70-90% of primary energy supply in some countries (UNDP, 2003; Karekezi, et al, 2002), and 86% of energy consumption (IPCC, 2003). The bulk of biomass energy used in sub-Saharan Africa is traditional biomass (UNDP, 2003). Variations within Africa exist, with biomass accounting for only 5% of energy consumption in North Africa and 15% in South Africa (IPCC, 2003).

Traditional Biomass Energy Technologies (TBTs) consist of, inefficient use of wood, charcoal, leaves, agricultural residues, animal/human waste & urban waste. The traditional biomass technologies are highly preferred in Africa because they readily available and meet energy needs of significant proportion of population – particularly rural poor in Africa. 996 million people in sub-Sahara Africa will rely on traditional biomass for cooking and heating in 2030 (Karekezi et. al., 2008). Some 575 million people in Sub-Saharan Africa depend solely upon traditional biomass fuels for primary energy, a figure that represents 76% of the region's population (IEA, 2006). The reliance upon traditional biomass fuels is magnified in rural areas, where more than 90% of the population in many countries depends upon these fuels. Firewood is an abundant source of energy but in some areas is under severe pressure, due to the demand for farmland as well as overuse in both the agro-industrial and domestic sectors.

The primary source of biomass energy is woodfuel—firewood and charcoal—but agricultural residues and animal wastes are used to a lesser extent where woodfuel is unavailable. This biomass is mainly used for cooking and space heating. Efficiencies of such uses are often low. For example, fuelwood is mostly burned in simple 3-stone stoves with very low thermal efficiencies between 5-20% (Wiskerke, 2008). Other negative impacts of these traditional uses are the emissions of greenhouse gases from incomplete combustion, indoor air pollution and related health effect, overuse of wood resources and related deforestation and the mainly female labour needed for fuelwood collection; see Section 2.

Modern and improved uses of biomass for bioenergy is could be a possible solution to increase the efficiency of bioenergy use, to combat energy poverty especially of modern energy carriers such as transport fuels and electricity and to contribute to rural development. However, bioenergy can also have negative environmental and social effects, e.g. displacement of food production and loss of biodiversity.

However, barriers to bioenergy expansion are set by factors including the resource potential and distribution, the efficiency of biomass conversion technologies, public acceptability; and land-use and environmental aspects. Most of these barriers to the increased use of bioenergy could be overcome by developing and deploying cost-effective conversion technologies, by developing and implementing improved dedicated bioenergy crop production systems, by establishing bioenergy markets and organizational structures and by valuing the environmental e.g. by carbon financing.

As a consequence, many development projects have targeted the use of biomass for energy while improving social and environmental conditions. This comprises the introduction of improved household stoves, the use of improved charcoal kilns and the use of modern bioenergy sources such as ethanol and biodiesel for transportation and the production of electricity from various sources. Other improvement options for household cooking are the switch to advanced fuels such as liquefied petroleum gas (LPG), electricity, and biofuels from vegetable oils, ethanol or biogas.

The objective of this report is to describe the state-of-the are of traditional biomass uses in Sub-Saharan Africa concentrating on the use of fuelwood, charcoal and agricultural residues as well as describing improved bioenergy systems for cooking and heating and for modern applications such as transportation fuels, process heat and electrification. Based on this recommendations on best practice bioenergy systems for Sub-Saharan Africa will be made within the COMPETE project.

2 Traditional biomass uses for energy

The diversity of fuels used in household cooking in Sub-Saharan Africa is representative of the complexities of the market. While a large fraction of households rely upon traditional fuels—those that the energy ladder would describe as “primitive” fuels, or, in the case of charcoal, transition fuels—a small percentage of households have begun using advanced fuels for cooking. The following sections describe the use of traditional biomass options for cooking in Sub-Saharan Africa.

2.1 Traditional Cooking Fuels - Firewood

In most Sub-Saharan African nations, firewood is the predominant fuel of choice in the majority of households (see Table 1). In rural settings, the fraction of the population that uses firewood is fairly consistent across countries, a result of its low cost and the lack of available alternatives. In urban areas, use of firewood as the primary fuel varies according to factors such as differences in price and the availability of alternatives. The combustion of firewood often takes place in open stoves and is thus characterized by low energy density and low total combustion energy efficiency—often between 10% and 20% (Bailis, 2004). In addition, the heat provided by combustion is difficult for the user to control in the open stove. Therefore, large masses must be burned.

The traditional cooking method is cooking on open fires or three-stone fires. For example, a survey conducted in February 2006 in Kenya showed that: 96.8 % of the population use firewood for cooking. 87.5 % of the population uses traditional three-stones cooking (Figure 1). 4.8% of the households used maendeleo stoves (improved firewood stove), which corroborated the findings of the Ministry of Energy study, 2002, in which the results showed that 4% of the population used the improved stoves. The average firewood consumption is 1.2 kg per person per day (ppd), while the national figure stands at 1.5 kg per ppd.

A wide variety of improved stoves is available, which have higher efficiencies, compared to the traditional three stone stove, see further Section 5.

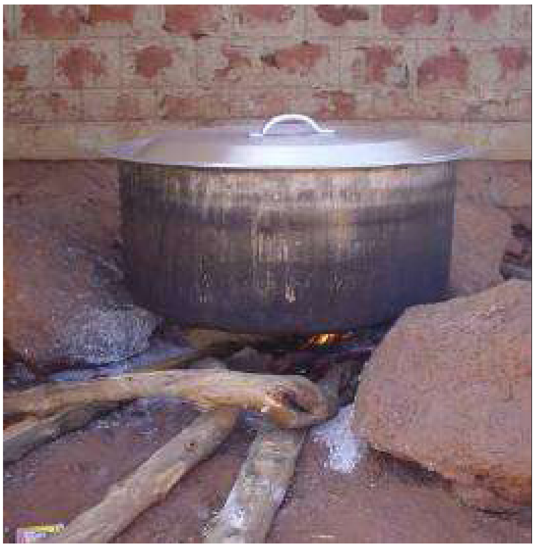


Figure 1: Three stone firewood stove (By surrounding the three-stone fire with a mud, concrete, ceramic, or metal wall-body, a combustion chamber is created and the open fire is transformed into an improved stove.)

The prevalence of firewood in the energy economy of Sub-Saharan Africa (Table 1) follows both from its widespread availability and its perceived low private cost. In rural areas, the apparent cost of energy from firewood to its consumers is zero, as it can be collected for free. The collection of firewood is gendered, as it is most often women who spend time collecting the wood. Thus, the private price of firewood often does not reflect the external and opportunity costs associated with its collection and combustion.

Table 1: Firewood Dependence for Selected Countries

	Percentage of Total Population		Percentage of Population Relying on Firewood		
Country	**Rural**	**Urban**	**Rural**	**Urban**	**Total**
Tanzania[a]	76.9%	23.1%	95.6%	26.7%	77.4%
Uganda[b]	87.7%	12.3%	91.3%	22.1%	81.6%
Senegal[c]	59.3%	40.7%	89.1%	15.9%	54.7%
Zambia[d]	65.3%	34.6%	87.7%	10.1%	60.9%
Malawi[e]	85.6%	14.4%	98.5%	69.0%	94.3%
Kenya[f]	64.1%	35.9%	88.4%	9.6%	68.8%

[a] TNBS 2006
[b] UBS 2006a; UBS 2006b
[c] ANSD, 2006
[d] CSOZ, 2000
[e] NSOM, 1998
[f] KNBS, 1999; UNCDB, 2007

2.2 Transition Cooking Fuels - Charcoal

Charcoal is another important fuel currently used for household cooking in developing nations. While information on charcoal use in the region is sparse, available estimates indicate that the fuel provides energy for a majority of urban households. In Kenya, it provides for 80% of urban households and 34 per cent of those in the rural areas (Republic of Kenya, 2002). In Kenya, the annual consumption of charcoal has been estimated at 2.4 million tonnes (Republic of Kenya, 2002) valued at Ksh 36 billion. The most recent estimates reported a figure of 1.6 million tonnes worth Ksh 32 billion (ESDA, 2005). At the 16% Value Added Tax charged by the Kenyan Government, this should contribute Ksh 5.12 billion in taxes every year.

The situation is similar in Tanzania, where 80% of the charcoal produced is used by urban households (Ngerageza, 2003). In Ethiopia, a wood energy survey of 1996/97 indicates that 230,000 tonnes of charcoal are used every year. Seventy per cent of the total production is used in towns, supplying 97% of household energy needs. In Uganda, biomass constitutes 90% of the total energy consumption (Republic of Uganda, 2002). Like in the other countries in the region, charcoal is mainly used in urban areas and its use, estimated to increase at 6% a year, is proportional to the rate of urbanization (Tumuhimbise, 2003). In Zambia, woodfuel supplies 68% of national energy requirements. A total of 0.7 million tonnes of charcoal is consumed annually and 85% of urban households are reported to use it. Charcoal use is reported to have increased by 4% between 1990 and 2000 (Chidumayo, et. al., 2002). Charcoal production and trade contributes to the economy by providing rural incomes, tax revenue and employment. It also saves foreign exchange that would otherwise be used to import fuel. In the Licuati region of Mozambique, for example, 65.4% of rural incomes are derived from charcoal. The World Bank/ESMAP employment estimates per TJ Energy consumed in person days indicate that charcoal creates between 200 and 350 jobs per TJ, LPG 10-20 and kerosene only. The figures suggest that promoting charcoal can create more jobs than the other forms of energy. In addition, planting trees for charcoal can be a profitable enterprise as shown in the case of Kakuzi (2003), where it costs Ksh 159 (60% of the retail price) to produce a bag of charcoal that is sold at Ksh 260, earning net revenue of Ksh 101 or 40% of the retail price. The charcoal industry in Kenya employs about 200,000 in production alone. In Uganda, production provides 20,000 jobs and generates more than Ush 36 billion (US$20 million) a year for rural people. The pattern is similar in the other countries in the region. However, despite its significant contribution, charcoal has been kept out of the formal economies of these countries, mainly because its importance is not well understood and appreciated.

In Africa, charcoal production and use is projected to increase from 19.1 Mtoe in 2010 to 30.8 Mtoe in 2030. Traditional charcoal production e.g the traditional earthen kiln is a particularly inefficient process, resulting in significant loss of energy in the conversion of woodfuel to charcoal (IEA, 1998). In 2004, energy losses in charcoal conversion using the traditional earth kiln technologies were 30 Mtoe per year and this figure is projected to be 53 Mtoe in 2010 (Karekezi, 2004). For example, using the earth mound kiln, about 12% efficiency is normal in Zambia (Kalumiana and Shakachite, 2003), 11-15% in Tanzania (Ngerageza, 2003), 8-12% in Ethiopia (Yigard, 2003) and 9-12% in Kenya (Theuri, 2003). In the most efficient kilns, like those used on plantations, an efficiency of 28% (Kakuzi, 2003) has been achieved. In Laikipia, Kenya, the retort kilns have attained 35-45%. In Mozambique, efficiency was found to range from 14 to 20% (Pereira, et. al., 2001). Conventional charcoal stoves have an efficiency of 15–18% (Malimbwi *et al.* 2007), which is considerably higher than a conventional 3-stone fuelwood stove. Nevertheless, when considering a fuelwood stove efficiency of 7% and an energy content of 18 MJ/kg and 32 MJ/kg for air dry wood and charcoal respectively (Rosillo-Calle *et al.* 2007), one needs 26% more wood when cooking on charcoal as compared to directly cooking on fuelwood.

While its role in meeting the energy needs of the rural community is typically small, it is often widely used in urban areas (see Table 1). In many respects, its characteristics as a cooking fuel make it more desirable for household use than firewood: it emits fewer pollutants, has an higher energy content, and is simpler to transport. Because of its advantages over firewood, there have been a number of efforts to promote its use in household cooking; nonetheless, in comparison to clean cooking fuels, it remains an inefficient fuel and is less than ideal for household cooking.

Figure 2: The traditional metallic charcoal stove

So the overall system efficiency is quite low; about 5% of the energy in the original biomass is converted to useful energy for cooking using traditional earth kilns (Davidson, 1992). As a result, large quantities of biomass must be used to manufacture enough fuel to meet the energy demand of the urban population. In Nairobi, for example, it is estimated that a household that relies exclusively upon charcoal will consume between 240kg and 600kg of charcoal annually; the input of biomass required in the production of this charcoal is 1.5 to 3.5 tons (Kammen, 2006).

Table 2: Costs, efficiencies and lifetimes of various cooking stoves and the related cost of energy, in terms of utilized heat for conditions in East Shinyanga, Tanzania. (Source: Wiskerke, 2008)

Energy carrier	Stove type	Efficiency	Cost (US$)	Lifetime	Cost of heat (US$/$GJ_H$)
Wood	3-stone stove	7%	free	-	28
Wood	(Improved) mud stove	22.5%	1.43	2 months	9
Wood	(Improved) burned brick stove	29%	33.20	5 years	7
Charcoal	Traditional stove	16.5%	1.66	3 years	35 Legal 21 Illegal
Charcoal	Improved stove	45%	8.00	3 years	13 Legal 8 Illegal
Kerosene	Kerosene stove	38%	12.45	3 years	95
Electricity	Electricity stove	68%	49.80	5 years	42

2.3 Impacts of traditional biomass uses

2.3.1 Carbon impacts

Even where traditional biomass is harvested sustainably, the woodfuels would not be carbon neutral due to their incomplete combustion—the idealized fuel cycle in which all the carbon is converted to carbon dioxide is not a realistic model. Instead, due to incomplete combustion, carbon is released in other forms, including methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO) and non-methane hydrocarbons (NMHC). These compounds are referred to as products of incomplete combustion (PIC) and have much higher global warming potential than carbon dioxide (i.e. they have a greater climate change impact). According to the IPCC Fourth Assessment Report (2007), the 100-year global warming potentials of methane and nitrous oxide are 25 and 298 times that of carbon, respectively. Because of the incomplete combustion of woodfuels, between ten and twenty percent of the carbon released is in the form of PIC (Smith et al., 2000a). This number, the molar ratio of PIC emitted to total carbon emitted, is defined by researchers as the k-factor of a fuel and it varies based upon the technology used with the fuel. Alternative cooking fuels typically have much lower k-factors than woodfuel (see Table 3).

Table 3: K-factors for Various Cooking Fuels. (Source: *Smith et al*., 2000a)

Fuel	k-factor
Woodfuel	0.1-0.2
Kerosene (wick stove)	0.051
Kerosene (pressure stove)	0.022
LPG	0.0231
Biogas	0.00562

The potential to reduce carbon output in Sub-Saharan Africa by shifting to clean cooking fuels is significant. Aside from their low k-factor, fossil fuels have several other advantages over woodfuels: a higher energy density, a higher nominal combustion efficiency, and a higher heat transfer efficiency. These factors offset their higher carbon density, as both LPG and kerosene produce less carbon per unit of useful energy than woodfuel. At the same time, because the k-factor is lower, even less of the carbon is released as PIC.

Given the current unsustainable pattern of woodfuel extraction, a transition to petroleum-based fuels would reduce net carbon emissions. Emissions scenarios based upon this shift project a decrease in cumulative emissions by 2050 by between 1 and 10% (this projection is based upon a combined use of kerosene and LPG to meet household cooking needs) (Bailis et al., 2005). It is, however, worth noting that if woodfuels were used in a sustainable manner and with higher efficiency, the carbon emissions would be of comparable magnitude to—and generally less than—that of petroleum-based fuels.

2.3.2 Indoor Air Pollution

The woodfuels that most of Africa's households use for cooking are a major source of indoor air pollution. The inefficient and incomplete combustion of woodfuels releases a number of hazardous pollutants, including carbon monoxide, sulphur and nitrogen oxides, and particulate matter. In many households, poor ventilation exacerbates the effects of these pollutants, and women and children are often exposed to them at significant levels for between three and seven hours each day (Bruce et al., 2002). Such prolonged exposure to indoor air pollution has been implicated in the increased incidence of a number of respiratory diseases in developing nations.

The causal relationship between high concentrations of particulate matter and acute respiratory infections (ARI) has been established in a number of studies and is thoroughly reviewed in Smith et al. (2000b). Accounting for an estimated 10% of disease-related deaths in Africa (Bruce et al., 2002), ARI poses a major threat to women and children in developing nations. Children are particularly susceptible to contracting acute lower respiratory infections (ALRI)—a specific type of ARI—which is the leading cause of death for children younger than five (Bruce et al., 2002). A recent study by Ezzati and Kammen (2001) that monitored 55 rural Kenyan households that relied primarily on firewood and charcoal has quantified the exposure-response relationship between the incidence of ARI and the indoor concentration of particulate matter, which is a concave curve that increases with exposure. The potential to reduce exposure—and, by proxy, ARI—is significant: a follow-up study (Ezzati and Kammen, 2002) found that a complete transition to charcoal would reduce the incidence of ARI by up to 65%. Clean cooking fuels offer the potential for even greater reductions. Gas burning stoves emit up to 50 times fewer pollutants than biomass burning stoves (Smith et al., 2000b); as a result, the associated incidence of ARI would be expected to drop considerably.

Several other diseases have been attributed to exposure to indoor air pollution from solid biomass fuels. Smoke produced in the combustion of firewood deposits carbon in the lungs and is known to cause chronic bronchitis, emphysema, and chronic obstructive pulmonary disease. Several studies have also linked childhood exposure to the smoke with asthma, though others have concluded that there is no association between the two.

2.3.3 Socioeconomic impacts of traditional biomass

In rural communities that rely almost exclusively upon solid biomass for cooking fuel, the burden of firewood collection falls primarily upon women and, to a lesser extent, young girls. Women gather firewood on foot, often walking long distances with heavy loads; the International Energy Agency (IEA, 2006) reports that the average load of firewood in Sub-Saharan Africa is 20kg. The task of collecting firewood has become an increasing burden in recent years as a result of trends in deforestation, which has necessitated further travel for wood collection in many areas.

The amount of time spent and distance travelled in the collection of firewood varies based upon the region, but most studies have found that women spend a significant portion of their days collecting firewood. A survey of 30 households near Lake Malawi found a mean distance to a viable firewood source of 2.1km, resulting in a mean trip length of 241 minutes and mean time spent collecting wood per day of 63 minutes (Biran et al., 2004). The results of a study of three villages in northern Kenya suggest that women in the region spend an average of 70 minutes per day collecting firewood (McPeak, 2002). In Tanzania, the roundtrip distance for firewood collection varies from just over 1 km to 10.5 km (IEA, 2002).

3 Biodiesel

3.1 Use of pure plant oil

Jatropha oil can also be used for running diesel engines. For example, Lister engines can be used to drive grain mills and water pumps. These inexpensive pre-combustion chamber diesel engines of Indian origin require only the addition of a fuel filter to be able to run on pure Jatropha oil, thus eliminating the need for gasoil entirely. Furthermore, at maximal load conditions the Jatropha oil gives even better results than gasoil because of its high oxygen content. The oil can also be used as a lubricant in these engines.

In equivalent terms, the energy needed to produce Jatropha oil in mechanical presses amounts to less than 10% of the oil obtained. Because Jatropha oil can be produced inexpensively, it can also be sold at prices lower than gasoil's official price at the petrol stations. Even more important than the price is the possibility f local energy production, because of the periodic unavailability of gas oil in the rural areas caused by lack of road access during rainy season.

3.2 Use and production of biodiesel from vegetable oils

3.2.1 Overview

Biodiesel is a term used to describe a methyl ester produced from a vegetable oil or animal fat. Oils and fats have similar energy content per liter to petroleum diesel, but they have one especially important difference. Vegetable oils and animal fats usually have a significantly higher viscosity – they are thicker. Rudolf Diesel designed his first engine to run on peanut oil but most "diesel" engines since then have been designed to run on thinner petroleum diesel. Since they were designed to run on a thin fuel, difficulties can arise if they are operated with fuels thicker than they were designed for.

To overcome this, it was found that reducing the viscosity of vegetable oils allows them to be used in almost every engine designed to run on petroleum diesel. The most common way of reducing the viscosity is by converting the vegetable oils into methyl esters. Vegetable oil methyl esters are produced by reacting 10 parts of vegetable oils with 1 part of methanol. The products of the reaction are 10 parts of vegetable oil methyl ester (biodiesel) and 1 part of glycerin. The resulting methyl esters can be used in practically any diesel engine with minimal - if any - modification. They have very similar energy content per liter to petroleum diesel and a very similar viscosity. However, unlike petroleum diesel they are no more poisonous than vegetable oils and are quickly biodegradable.

3.2.2 Feedstock

Biodiesel can generally be made from any vegetable oil or animal fat – fresh and high quality or old and low quality. All vegetable oils and animal fats are made up of different proportions of the same fatty acid molecules. A good composition, or blend, of fatty acid molecules results in high quality biodiesel, regardless of which source the individual molecules came from.

Table 4: Fatty acid profiles of various vegetable oils

Fatty acid types	Rapeseed	Soy	Sunflower	Palm	Coconut	Jatropha
8:0	-	-		-	7.0%	-
10:0	-	-		-	5.7%	-
12:0	-	-		-	42.4%	-
14:0	-	-		1.3%	18.1%	-
16:0	6.2%	13.0%	8.0%	44.7%	11.3%	17.7%
18:0	2.2%	4.9%	4.7%	5.4%	4.2%	7.9%
20:0	0.9%	0.5%	-	0.5%	-	-
22:0	-	0.8%	1.2%	-	-	-
18:1	55.5%	23.9%	28.9%	37.2%	8.7%	37.8%
18:2	22.6%	49.6%	56.5%	10.8%	2.5%	36.6%
18:3	12.6%	7.3%	0.7%	-	-	-
Total	100%	100%	100%	100%	100%	100%

There is a very wide range of feedstocks from which to produce biodiesel:

- Widely available oilseeds include: rapeseed oil, palm oil, soybean oil, sunflower seed oil, coconut oil, linseed oil, cotton seed oil, ground nut oil, castor oil, sesame seed oil.
- Other oil crops are: corn oil, olive oil, hemp oil and milk thistle oil.
- New oilseed varieties: high oleic sunflower seed oil, high oleic rapeseed oil, low linolenic rapeseed oil, high erucic acid rapeseed oil.
- Non-food oil crops: jatropha oil, cornus oil, acrocomia oil, pongamia oil, babaçu, buriti, dendê and palmiste.
- Animal fats: beef tallow, pig lard, poultry fats, rendered fats.
- Used oils: used frying oil

One point to note when using vegetable oils to produce fuels is that the non-oil containing parts of the plant are not wasted. The “cake” that is left over after the oil has been pressed out of the seeds or nuts is usually used as animal feed. The stalks are often tilled into the earth or left on the field, where they serve as a fertilizer for the next crop. Typically, all parts of the plant are used productively and nothing goes unused. If all portions of the plant were converted into a fuel, additional fertilizers would need to be applied and additional animal feed would need to be imported.

3.2.3 Production process

The basic production process for biodiesel is very simple. In the main process reaction the oil (triglyceride) reacts with methanol in the presence of an alkaline catalyst (e.g. sodium methylate) and is split into Fatty Acid Methyl Ester (FAME, or biodiesel) and glycerine. Any free fatty acids, if present in the feedstock, can be separated and esterified in an acidic environment to produce biodiesel from these as well. After some cleaning steps, the biodiesel achieves the required quality.

This reaction can be carried out in a bathtub or in an industrial-scale production plant. The mass balance of the reaction is generally the same regardless of facility size. However, the amount of utilities used, the efficiency with which the biodiesel molecules are separated from the glycerin molecules, the cost of the production equipment compared to the capacity, etc. do vary. For these reasons, larger production facilities are generally able to produce biodiesel more cheaply and efficiently per liter than smaller facilities.

The quality requirements placed on the fuel must also be considered during the production process. Engine manufacturers are continually trying to decrease fuel consumption and emissions. This requires ever tighter tolerances in the engines and ever tighter control over the fuel's physical and chemical properties. Older diesel engines are more tolerant of contaminants and slight impurities but over time, engines are becoming more demanding regarding fuel quality. Accurately controlling the amount of particulates in the biodiesel, the amount of water, the amount of glycerin, and the amount of unconverted oil molecules may be important depending on which engines the biodiesel will be used in. If the fuel quality requirements are high or if international quality standards must be met, these can be much more easily achieved in industrial-scale plants.

3.2.4 Use

A biodiesel with as little particulate and liquid contaminants as petroleum diesel can generally be used in any diesel engine – including the most modern produced anywhere in the world. When using biodiesel in an engine designed for petroleum diesel, three points should be especially taken into account:

- Biodiesel has much better detergent properties than petroleum diesel, so it keeps the fuel system much cleaner. If an engine has been run on petroleum diesel, deposits may have formed in the fuel tank which biodiesel may flush into the fuel filter. For this reason, the fuel filter should be changed more frequently if biodiesel is used in an engine previously run on petroleum diesel.
- Biodiesel can soften rubber fuel lines and seals more than petroleum diesel. Before running an engine on biodiesel, one should check with the manufacturer whether the rubber parts in the fuel system are compatible with biodiesel. Many manufacturers have used rubber components that are compatible with biodiesel for many decades and lists are available

with manufacturer approvals. If the fuel lines and seals are not biodiesel-compatible, they should be replaced before running the engine on pure biodiesel or blends over 7%.

- Depending on the vegetable oil or animal fat the biodiesel was produced from, it may freeze at higher temperatures than petroleum diesel. For this reason, extra care should be taken when using biodiesel in low-temperature environments.

3.2.5 Outlook

Biodiesel has several advantages that make it a very attractive fuel. The raw materials used to produce it can be grown locally. The facilities used to produce it are simple and inexpensive compared with any other diesel fuel (petroleum diesel, biomass to liquid, gas to liquid, coal to liquid, etc.). Biodiesel can be used in practically any diesel engine with minimal or no modifications and due to this, it is a valuable product that can be sold to generate income.

3.3 Use and production of liquid biofuels from synthesis gas

The term Biomass to liquids (BtL) is applied to Liquid Synthetic fuels made from biomass through thermo chemical routes. The objective is to produce liquid fuel components that are similar to those of current fossil-derived petrol (gasoline) and diesel fuels. Unlike the first-generation biofuels (biodiesel, ethanol fuel), BtL uses not only those parts of the plant rich in energy like sugar and starch, but the whole of the plant (also the ligno-cellulosic component). As a result, even lower greenhouse gas emissions and a significantly more efficient and eco-friendly use of crop areas can be achieved. There is no need to carry out an expensive conversion of petrol stations or motor engines. Biomass to Liquid (BtL) is one of the most promising technologies in the fuel sector currently still at a demonstration stage.

BtL-fuels may be produced from almost any type of low-moisture biomass, residues or organic wastes such as short rotation trees, perennial grasses, straw, forest thinnings, bark from paper-pulp production, bagasse, waste paper or reclaimed wood or fibre based-composites. It is estimated that over $4m^3$ of BtL-fuels can be produced per hectare of land per year. Hence, in future if 4-6 million hectares of land were used to grow energy crops, one could replace 20-25 % of the EU-27 liquid transport fuel currently used.

The advantage of the BtL route to liquid transport fuels lies in the ability to use almost any type of biomass, with little pre-treatment other than moisture control. This is because the feedstock is gasified in the first stage of the process. The gas produced is then treated further to clean it, remove tars, particulates and gaseous contaminants, and to adjust the ratio of the required gases (hydrogen and carbon monoxide) to that required. The result is a balanced syngas that can be used in the second, catalytic, stage. Syngas may also be obtained by pyrolysis via charcoal. The hot charcoal is then reacted with steam to produce watergas (around mixture 50% H2-50%CO). However, the BtL technology is still at a demonstration stage, and it is therefore now necessary to pave the way for future large-scale production.

3.3.1 Main concept of Biomass to Liquid process

The process uses the whole plant to improve the carbon dioxide balance and increase yield.

The *Fischer Tropsch* process is used to produce synfuels from gasified biomass. While biodiesel and bio-ethanol production so far only use parts of a plant, i.e. oil, sugar, starch or cellulose, BtL production uses the whole plant which is gasified by thermo-chemical process. The result is that for BtL biofuel production, less land area is required per unit of energy produced compared with biodiesel or bio-ethanol.

The Fischer-Tropsch process is a catalysed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms:

$$(2n+1)H_2 + n(CO) \rightarrow C_nH_{2n+2} + nH_2O$$

Generally the catalysts used, in the process, are based on iron and cobalt. The FT process is an established technology and is already applied on a large scale from coal or natural gas. Developed in the 1920s in Germany, it was used by both Germany and Japan during World War II and later by South Africa and to a lesser extent in the United States.

One problem is the high capital cost of the multistage process. This may be greater when biomass is used as feedstock for logistic problems, since the scale of operation may be limited by the distance over which biomass can be transported to the factory at an economic price. Hence, the economy of scale effect is decreased compared to large coal or gas-based operation. Running and maintenance costs are also comparatively high.

Flash Pyrolysis - producing bio-oil, char and gas. It is a thermochemical process which under conditions of medium temperature (450-600ºC) and short residence time (< 1 sec.) converts organic materials to char, tar and gas. Tar, a homogeneous mixture of organics and water commonly referred to as Bio-Oil, is a good energy carrier and may be used in existing combustors and distribution systems for fossil heavy fuel, while gas can be utilized for process heat.

Fluid bed and ablative reactors are the two principal technologies now available for flash pyrolysis. In the former, biomass is introduced into a bed of hot fluidized inert material, usually sand. Although a well-known technology, fluid beds do have several disadvantages including the requirement for a large flow of inert gas for heat transport and fluidization, a relatively poor capacity/volume ratio and the need for small particle size feed.

Catalytic depolymerization (CDP) - using heat and catalysts to separate usable diesel fuel from hydrocarbon wastes. The CDP is the alternative route to produce liquid transportation fuel from biomass. This process is principally based on direct liquefaction of biomass. In this process, the long chain hydrocarbons or organic materials are cracked into light bio-crude oil with the aid of ion exchanged catalysts under a temperature of less than 500℃ and atmospheric pressure.

Since there are no exact chemical equations for the catalytic depolymerisation process, the results of this process can be obtained only from the experimental work on the specific feedstock. There are many studies for investigation of liquid fuel production form CDP available.

Advantages of FT-diesel and CDP-diesel are that they are high quality and ultra clean transportation fuel with very low sulphur content and aromatic compounds. FT-Diesel and diesel derived from CDP can be directly used in vehicles and existing infrastructures without any adaptation. However, FT-diesel is more expensive that CDP-diesel.

3.3.2 Outlook

Although the processes for production of BtL are well known and have been applied using fossil-feedstocks, such as methane (GtL) or coal, commercial biofuels based on these processes and technolgies are not currently commercially available. However, BtL RD&D in Europe is gathering momentum, and the world's first commercial BtL Plant is now under construction in Frieberg Saxony (using Choren Carbo-V ® Process).

Box 1: Properties of biodiesel from different vegetable oils

As was discussed in section 2.2.2, all vegetable oils and animal fats are made up of different proportions of the same fatty acid molecules. Each vegetable oil has a typical fatty acid profile and each profile results in a biodiesel with different properties. Fatty acid profiles vary somewhat due to growing conditions, natural variation, etc., but the following table shows typical properties of biodiesel produced from various plants.

	Freezing point (CFPP)	Viscosity (at 40° C)	Stability (iodine value)	Calorific value
units	° C	mm^2/sec		MJ/kg
EN 14214 standard requirements	seasonal	3.5 – 5.0	≤ 120	-
Coconut biodiesel	- 9	2.8	12	35.6
Palm biodiesel	+ 11	4.5	51	37.0
Jatropha biodiesel	- 3	4.3	96	37.1

Milk thistle biodiesel	+ 10	4.9	110	37.1
Rapeseed biodiesel	- 10	4.8	116	37.3
Sunflower biodiesel	- 3	4.2	125	37.1
Soy biodiesel	- 5	4.3	125	37.1
Petroleum diesel	- 19	3.1	-	43.1

No single plant has a fatty acid profile that gives optimal quality across all possible parameters. Breeding can create plants whose fatty acid profiles are closer to the ideal and blending the oils of various plants can also create the qualities desired while at the same time potentially decreasing costs.

When looking for the ideal fatty acid profile, it is important to note that there are tradeoffs between different parameters. All fatty acid molecules have two oxygen atoms plus varying numbers of hydrogen and carbon atoms. The longer the molecule, the lower the relative proportion of oxygen and therefore the higher the calorific value (petroleum diesel, for comparison, is a hydrocarbon completely without oxygen and therefore with a high calorific value). However, the longer the molecule, the higher the freezing point of the resulting biodiesel will be. Freezing point and calorific value are two somewhat opposing goals when searching for the "ideal" fatty acid profile.

The number of double bonds in the fatty acid molecule also impacts the freezing point and it impacts the stability of the molecule as well. Double bonds, which make the oil "unsaturated", lower the freezing point of the resulting biodiesel, which is good, but they also make it less stable and less suited for long-term storage, which is not good.

There is no one ideal vegetable oil from which to make biodiesel and the ideal fatty acid profile will be the result of the best compromise. The best compromise may vary depending on geography and season.

In general, plants whose oils have relatively short molecules and few double bonds will produce a biodiesel with excellent properties in most conditions. The biodiesel produced from such oils will be stable and will not freeze during cool nights. The relatively high percentage of oxygen will reduce the calorific value compared to petroleum diesel per liter, but the oxygen in the fuel may cause the combustion to be more efficient, making up for at least some of the lower calorific value. There is no one ideal vegetable oil or fatty acid profile, but several plants available today produce good compromises that can be further improved by breeding and by blending.

Source: ABI

4 Bioethanol

4.1 Production of ethanol from sugar/starch plants

Ethanol currently accounts for more than 90% of total biofuel production with 80% produced from sugar cane and maize (IEA, 2008). From 2000 – 2005 the global fuel ethanol production doubled (WWI, 2006). Furthermore, Brazil exported in 2004-05 2.5 billion litres of ethanol with main destinations India (23.1%) and USA (20.2%) (Walter, 2006).

Ethanol is a biofuel that is used as a replacement for approximately 3% of the fossil-based gasoline consumed in the world today. It is used in motor engines as it has a motor octane number of 98 - which exceeds that of gasoline (octane number of 80) – and has a lower vapour pressure providing lower evaporative emissions (Goldemberg, 2008). Other characteristics of ethanol include: lower flammability in air is than that of gasoline which and anhydrous ethanol has lower and higher heating values of 21.2 and 23.4 MJ/liter, respectively; for gasoline the values are 30.1 and 34.9 MJ/liter (Goldemberg, 2008).

Fuel ethanol or ethyl alcohol is a product of the fermenting and distillation process of simple sugars. Blends in gasoline range from E20 (20% ethanol and 80% gasoline) to E100 (100% ethanol) with E85 (85% ethanol and 15% gasoline) being the most common and widespread (Tilbury, 2007).

4.1.1 Cassava based ethanol

Ethanol can be produced from starch crop. One option in the African context is the production of ethanol from cassava. Cassava fresh roots contain around 30% carbohydrates, whereas dried chips can have up to 60%, therefore they represent some of the richest fermentable feedstock for ethanol production. Several countries have announced large scale development programs for cassava based ethanol production; such as Thailand, Nigeria and China.

The process to obtain ethanol from cassava includes the following steps:

- *Feedstock pretreatment:* washing and crushing;
- *Pulp cooking:* this step is necessary to remove cyanogenic compounds;
- *Saccharification:* this can be achieved by either mixing the pulp with hydrochloric acid or sulphuric acid in pressure cookers or by partial hydrolysis and enzymatic treatment. With these treatments the starch contained in the pulp is transformed into fermentable sugars.
- *Neutralization:* buffering salts such as sodium dicarbonate (Na_2CO_3) are added to the mixture to remove the free acids and bring the pH value in the range 5.0-7.0, that is compatible with the activity of yeasts that carry on fermentation;

- *Fermentation:* this phase lasts for 3-4 days and produces a solution containing 6-12% ethanol.
- *Distillation:* This is obtained by treating the fermented solution (containing also some solid residues) in a multi-column system where ethanol is evaporated at 78°C and condensed into liquid several times. At this stage the concentration of ethanol in the solution can achieve 95%.
- *Dehydration:* fuel ethanol must have 99.75% concentration. To remove excess water, dehydration can be performed by mixing the solution with organic compounds (i.e. cyclohexhane), which are then recovered and reused or by adopting a "molecular sieve" that separates water from alcohol.

NEV (Net Energy Value) is a parameter often used to assess a biofuels' energy balance by means of measuring the energy content of ethanol minus the net energy used in the production process. According to a recent research by Thu Lan Thi Nguyen, Shabbir H. Gheewala, and Savitri Garivait (Thonburi University of Technology, Thailand), the NEV of cassava-based ethanol was estimated at 10.22 megajoules per liter (MJ/l), whereas the same assessment for corn showed a maximum NEV of around 4.51 MJ/l, meaning that cassava is more than two times as efficient than corn.

Box 2: Regional Biofuels Programmes in Sub-Saharan Africa

Malawi - ethanol production started in 1982 at Dwangwa Sugar Mill, second ethanol plant built in 2004 at Nchalo Sugar Mill, both plants have combined capacity of 30 million litres per year, produced 18.6 million litres in 2006. Over 224 million litres have been blended with petrol since early 1980s, attained 20% fuel blending.

Ethiopia – produces 8 million litres per year of ethanol from molasses, Minister of Mines and Energy announced a policy to begin blending 5% ethanol into the country's transport petrol pipeline, started this month (Sept, 2008).

Uganda - produces large quantities of sugar, grain, & oil crops that can be used for ethanol and biodiesel production, but has yet to develop a comprehensive program for harnessing this potential. Large quantities of crude ethanol are already being produced from molasses, cassava, sorghum, and millet, but it is being consumed as beverage alcohol.

Tanzania - very well situated for large biofuels production, climate & soils suitable to grow a range of biofuels feedstocks, estimated to have over 40 million hectares of agricultural land that is not being fully utilized and could be used for biofuels; Ministry of Energy & Minerals looking for aid from Sweden to fund research on biofuel products.

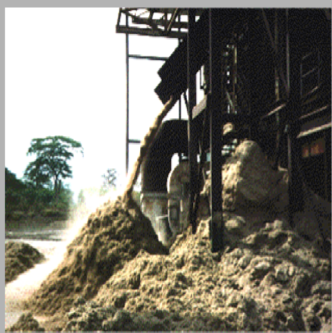
Sudan - Kenana Sugar Company has a ten-year expansion plan to produce 200,000 litres of ethanol per day from molasses

South Africa - accounts for ~70% of total ethanol production in Africa, although most of that has been of the synthetic kind derived from coal and gas, two large ethanol plants have a current production capacity of 97 million litres per year. Three large biodiesel plants are now being planned, with a total production capacity of more than 300 million litres per year

Kenya -. The Agro Chemical & Food Corporation (ACFC) established in 1978 – with the objective of utilizing surplus molasses from sugar industry to produce ethanol. ACFC installed capacity of 60,000 liters per day, daily average of 45,000 litres per day (lpd). Ethanol production revived in 2001 through Kisumu Ethanol Plant in Western Kenya with Energem owning 55% of the company. The company Produces approximately 60,000 (liters per day) lpd of industrial ethanol. Other products include: beverage grade, yeast, carbon dioxide, alcohol, portable alcohol for beverages and chemical industries. Market for the ethanol include: local market, Uganda, Rwanda, and Central Africa. Plans are underway for expansion, production projection 230,000 lpd (Karekezi et. al., 2008).

Current and planned ethanol production capacity in Kenya

Production	**ACFC**	**KEP**	**Mumias**	**Total**
Current capacity	60,000	65,000	0	125,000
Current production	27,400	30,000	0	57,400
Current + planned production capacity	60,000	230,000	50,000	340,000


Source: Karekezi et. al., 2008 and ESD

Box 3: Experiences with ethanol production from cassava in Benin

Cassava is already used as a feedstock for ethanol production in Benin, a Chinese company named Yueken started a small industrial unit in 2002, which and is able to produce around 3.000 MT of ethanol form 10.000 MT of cassava.

Overview of Yueken distilleries at Savalou, Benin

In 2007 the Ministry of Energy Mines and Water of Benin commissioned a feasibility study (co-funded by the World Bank) with the aim of assessing the opportunities and constraints and the market potential for the production of bioethanol and biodiesel, and elaborating a Biofuel Action Plan for the country. The study is still in progress but the preliminary results showed that cassava may be one of the primary feedstock for bioethanol production, thanks to the following advantages:

- Cassava is well adapted to Benin's climate, it can be cultivated in all the agro-ecological regions except for the extreme north of the country, and is well known by farmers and well introduced into the traditional farming systems;
- The success of the PDRT in the dissemination of modern cultivation techniques, adoption of improved varieties, and support to the structuration of the supply and production chain are a good basis for the introduction of a more agro-industrial farming system for cassava.
- The roots can be harvested all year long and stocked for long time
- An average unitary ethanol yield of at least 2500 litres per hectare can be achieved with the current crop's productivity, if the steady trend of increase of productivity of the lat years continues, a foreseeable production of 3.500to 4.000 litres per hectare could be easily achieved (comparable to that of corn based ethanol but with a better energy balance).
- Despite the fundamental importance of cassava for the country's food security, significant excess of foodstuff was registered in the last years (1.771.076 tonnes over 3.110.000 in 2006-2007), so the impact of ethanol production on food prices and food security could be minimized;

Source: M. Cocchi, ETA

4.1.2 Ethanol from sugar cane and sweet sorghum

Sugar cane is considered the best feedstock for bio-ethanol showing the best energy balance and lowest production cost. This is due to the high photosynthetic efficiency of the sugar cane. The sugar cane stalks contain the cane juice from which sucrose is extracted and/or bio-ethanol is produced, and they are shipped to the sugar factory by truck or rail, marking the end of the agricultural stage and the start of the industrial stage of sugar-cane processing (Farioli et al, 2006).

Ethanol is a clean-burning alcohol fuel that is traditionally made through a biochemical processes based on fermentation of final molasses (C-molasses), from either of the previous two production stages (B-molasses and A-molasses) or from the cane juice, or in fact any mixture of them. In Brazil, it is common to use a mixture of cane juice and B-molasses. The output of the sugar factory is a brown granulated sugar known as “raw sugar” with a sucrose content varying from 94 to 99 %.

After preparation of a mash with the appropriate concentration of sugars and solids, the sugars are transformed into alcohol using yeasts as the catalyst. Fermentation takes four to 12 hours. The chemical reaction liberates a significant amount of CO2 and heat. The fermentation process can be conducted in batch or continuously, using open or closed fermentation tanks (Farioli et al, 2006).

Several technological advances are important to consider in configuring an ethanol factory. The first is continuous fermentation (through increased yeast concentration), which has become a valued alternative to batch processing. Continuous processing increases the productivity of fermentation, i.e. the amount of ethanol fermented per litre volume per hour. High productivity reduces the volume capacity required for fermentation tanks, thereby reducing costs. In distilleries (as well as in sugar factories), low steam utilisation technologies have been introduced through heat integration using waste heat in heat exchangers, which is then re-used to increase the temperature and/or pressure of other processes. Such an approach uses less steam and leaves more steam for electricity generation, thereby improving the economics of production (Goldemberg, 2008).

In the case of Africa, sugarcane is sometimes used in the brewing of illicit spirits is of interest because this represents local production of ethanol from sugarcane using indigenous knowledge (Woods et al, 2007).

Electricity from co-generation with bagasse, and ethanol for local energy supply, possibly as ethanol gel for household use, or for blending with petrol are considered. Enhancing cogeneration with bagasse reduces dependence on coal which is often used during off-season periods and may need to be imported (for those countries without local coal resources. It also generates more job opportunities in the cane fields if harvesting practices are changed so that trash and cane tops are also harvested (Woods et al, 2007).

The net energy balance for biofuel production can be defined as the ratio of the energy contained in a given volume of biofuel divided by the fossil energy required for its production (in the form of fertilizers, pesticides, diesel fuel spent in mechanized harvesting and the transportation of sugarcane to the processing mill). Goldemberg (2008) stresses that sugarcane is made up of three components: sucrose, bagasse, and tops and leaves. Bagasse contains one-third of the energy in the sugarcane, and is the source of all of the energy needed in the ethanol mills. The other two-thirds are split between sucrose and the tops and leaves. Therefore, the net energy balance for ethanol production is high, between 8.2 and 10 (for instance, corn ethanol is 1.3).

Water pollution is also a noted impact of cane processing. Here the main pollutants are water-borne organic matter and solids, which can affect groundwaters, rivers and wetlands (IIED,2004 in Woods et al, 2006).

The lack of investment and suitable infrastructure represent some of the major obstacles in global competitiveness of southern African countries in producing and exporting bio-ethanol and generating electricity for export to the grid on a commercially sustainable basis (Diaz-Chavez & Jamieson, 2008). The creation of rural-based bioenergy industries is appealing for a region that is predominantly rural. The process of economic integration among SADC members could potentially facilitate and benefit from the expanded production of modern biomass and biofuels (Johnson and Matsika, 2006).

According to a recent scoping study from E4tech (2006) for the DTI (BERR), southern (SADC) Africa and the rest of Africa have similar amounts of land available for sugar cane expansion. This was based on the assumption, validated by local experts from industry, academia and NGO's, that it could be feasible to expand sugar cane production from its current 0.7M ha to around 1.5M ha in the region within the next 10 to15 years (E4Tech, 2006). This would be enough to satisfy twice as much the current regional consumption of sugar and in addition produce up to 7.3 billion litres of bioethanol each year. This volume of bioethanol could replace around 30% of the gasoline required by the projected southern African gasoline vehicle fleet of 17 million cars by 2020. Alternatively, if blended into gasoline at a 10% rate, it could fuel between 50 and 60 million gasoline cars (E4tech, 2006; Diaz-Chavez & Jamieson, 2008).

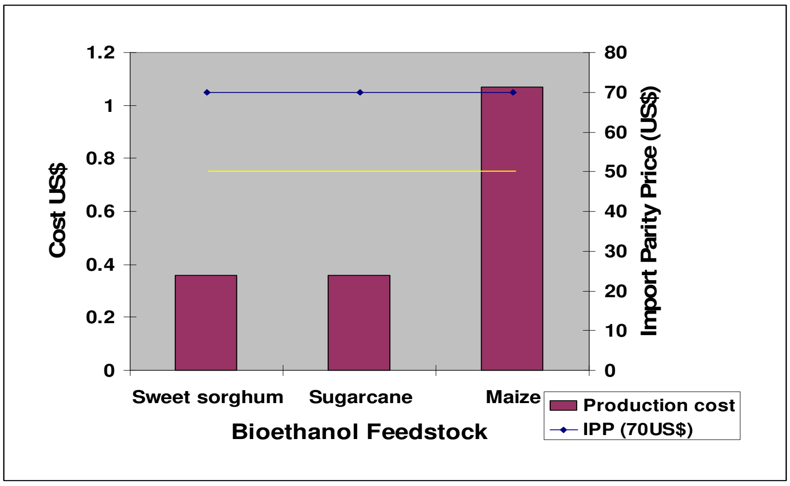


Figure 3 Comparison of production cost of ethanol from sweet sorghum, sugarcane and maize against import parity price of petrol (Source: CEEEZ, Zambia)

Another option for ethanol production from sugar crops is the production from sweet sorghum which could be highly efficient. When the average stem yields and ethanol recovery of the highest yielding varieties of sweet sorghums of about 150 t/ha and about 7,000 lit/ha for double cropping are compared against 85 to 90 t/ha of sugar cane and 5,600 lit/ha of ethanol produced, bioethanol produced from sweet sorghum is highly competitive.

4.2 Production of ethanol from lignocellulosic crops

Ethanol can be produced from lignocellulosic biomass; that is from any organic matter that contains a combination of lignin, cellulose and hemicelluloses. This includes agricultural wastes (e.g. straw), forestry products and wastes, energy crops (e.g. miscanthus, eucalyptus) and the biological component of municipal solid waste (MSW).

An overview of the production process of lignocellulosic biomass to ethanol is shown in Figure 4. Ethanol is produced by first breaking down the cellulose and hemicellulose into sugars, which can then be fermented. Lignocellulosic materials are more complex to break down than starch, and therefore require more advanced pre-treatment and conversion processes than those used in the production of ethanol from starch crops. A side benefit of this process is that the lignin residue and other unprocessed components can be used for co generation of electricity by combustion (large parts of the remaining of this section are based on IEA, 2009).

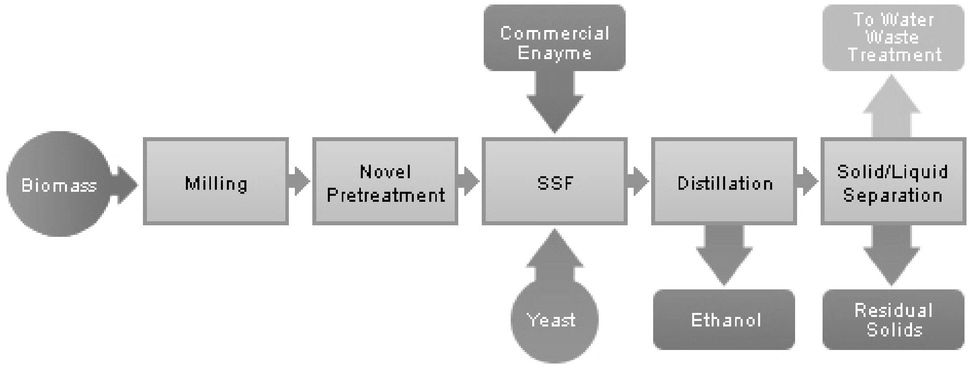


Figure 4 Overview of the production of ethanol from lignocellulosic biomass
(Source: Biopact, 2009).

Lignocellulosic ethanol is still at the demonstration stage. Technical barriers in in producing ethanol from lignocellulosic crops are the following:

- Pre-treatment of the substrate (the type of pre-treatment has consequences in the following conversions).
- Enzymatic hydrolysis of the substrate into fermentable sugars (depending on the pretreatment dedicated enzymatic saccharification of hemicellulose may be needed).
- Fermentation of the sugars to ethanol, and in particular the development of organisms that can tolerate the inhibitory compounds generated during pre-treatment.
- Product separation, as the residue tends to be difficult to separate into a solid and a liquid fraction.

Other research is directed towards the possibility of producing all required enzymes within the reactor vessel, thus using the same “microbial community” to produce both the enzymes that break down cellulose into sugars and those that ferment the sugars to ethanol. This "consolidated bioprocessing" is seen by many as the logical end-point in the evolution of biomass-conversion technology.

Although some of the individual stages involved in the process are already commercial (e.g. dilute acid pre-treatment, acid hydrolysis, fermentation and distillation), technological advances must be made in several process steps (e.g. enzymatic hydrolysis, fermentation of C5 sugars) in order to achieve the cost savings necessary to make lignocellulosic ethanol a competitive alternative (IEA, 2009). Most lignocellulosic ethanol R&D is currently taking place in the US, but there is interest in Northern Europe (with its large forestry resources) and in Brazil (where there is currently extensive 1st generation ethanol production from sugarcane with associated production of bagasse which could be used as a feedstock). Significant progress is being made in R&D and demonstration, and it is likely that commercial scale plants will be deployed over the next decade. See Figure 5 for estimated cost projections. For comparison: the wholesale price of conventional gasoline is ca. 0.40 US $ at an oil price of 40 US $ per barrel and 0.80 US $ at an oil price of 100 US $ per barrel (IEA 2008).

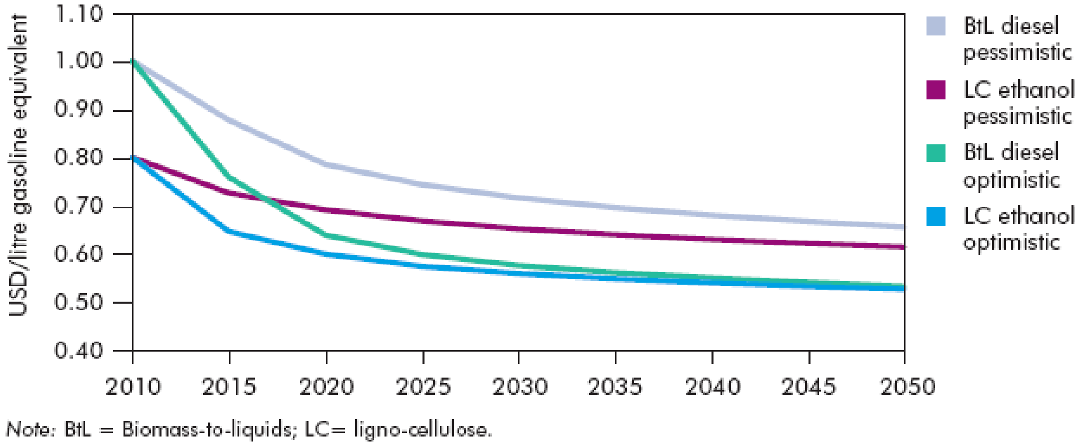


Figure 5: Cost projections for lignocellulosic ethanol and BTL diesel.
(Source: IEA, 2008).

A major limiting factor is the high investments costs of second generation biofuels plants. The total capital investments are estimated at circa 300 M€ for a large-scale plant (400 MWth input) in the present situation) to 750 M€ for a large-scale plant (2000 MWth input) which might become feasible in the coming decades (Hamelinck *et al.,* 2005). Second-generation biofuel technologies are primarily being developed in industrialized countries. Because of this and because of the high investment costs and risks of investing in developing countries it can be expected that second-generation ethanol plants will most likely be build in industrialized countries.

However, Africa may become an important low cost producer and exporter of lignocellulosic biomass to industrialized countries, see Table 5.

Table 5: The total estimated geographical potential of energy crops for the year 2050, at abandoned agricultural land and rest land and the estimated geographical potential at various cut-off costs for the four land-use scenarios (Source: Hoogwijk et al., 2009)

IPCC scenario →	A1				A2				B1				B2			
	<$1 GJ^{-1}	<$2 GJ^{-1}	<$4 GJ^{-1}	potential (EJ yr^{-1})	<$1 GJ^{-1}	<$2 GJ^{-1}	<$4 GJ^{-1}	potential (EJ yr^{-1})	<$1 GJ^{-1}	<$2 GJ^{-1}	<$4 GJ^{-1}	potential (EJ yr^{-1})	<$1 GJ^{-1}	<$2 GJ^{-1}	<$4 GJ^{-1}	potential (EJ yr^{-1})
Canada	0	11,4	14,3	18	0	7,9	9,4	12	0	11,1	12,1	14	0	10	11,1	13
USA	0	17,8	34	53	0	6,9	18,7	33	0	24,5	32,9	36	0	27,6	39,4	49
Central America	0	7	13	17	0	2	2,9	4	0	4,1	7,6	11	0	1,6	3,3	5
South America	0	11,7	73,5	87	0	5,3	14,8	24	0	27,6	60,7	63	0	6,1	32,7	43
Northern Africa	0	0,9	2	5	0	0,7	1,3	4	0	0,7	1,5	3	0	0,7	1	2
Western Africa	6,6	26,4	28,5	50	7,9	14,6	15,5	23	1,2	13,3	13,7	27	1,4	4,5	4,6	6
Eastern Africa	8,1	23,8	24,4	41	3,6	6,2	6,4	16	2,6	13,9	14,1	22	0,9	1,8	1,8	5
Southern Africa	0	12,5	16,6	43	0,1	0,3	0,7	10	0	11,7	12,6	29	0,1	0,2	0,4	2
OECD Europe	0	3	11,5	14	0	5,6	12,5	14	0	2,7	9,1	9	0	6,9	15,4	16
Eastern Europe	0	6,8	8,9	9	0	6,2	6,3	8	0	7,9	8	8	0	7,6	8,2	9
Former USSR	0	78,6	84,9	127	0,8	41,9	46,6	68	0	66,9	69	88	0	60,1	61,7	78
Middle East	0	0,1	3	13	0	0	1,3	8	0	0	2	4	0	0	1,4	3
South Asia	0,1	12,1	15,3	27	0,6	8,2	9,8	14	0,1	6,4	8,3	14	0	1,4	2,8	6
East Asia	0	16,3	63,6	107	0	0	5,8	23	0	49,8	61,1	77	0	0	21,4	46
South-East Asia	0	8,8	9,7	10	0	6,9	7	7	0	2,9	3	3	0	2,5	3,5	4
Oceania	0,7	33,4	35,2	55	1,6	16,6	18	34	10,4	28,1	28,6	35	5,5	24,3	24,8	30
Japan	0	0	0,1	0	0	0	0	0	0	0	0,1	0	0	0	0,2	0
Global	16	271	439	675	15	130	177	302	14	272	344	443	8	155	233	316

Table 5 shows that Africa has the potential to become an important producer and exporter of raw biomass produced on abandoned and rest land abandoned and rest land. Rest land is thereby defined as all remaining non-productive land, excluding bioreserves, forest, agricultural and urban areas and is calculated after satisfying the demand for food, fodder and forestry products. It is found that Eastern and Western Africa has the lowest-cost largest potential (below \$1 GJ^{-1}). Regions that are assumed to be able to produce significantly at costs below \$2 GJ^{-1} are, among others, West and East Africa. At these cost levels, large scale ethanol production is expected to become competitive with conventional gasoline, assuming that technological developments will be stimulated.

5 Improved traditional biomass uses for energy

In this section improved biomass energy technologies are discussed, which consist of improved and efficient technologies for direct combustion of biomass, such as improved cooking/heating stoves, and improved biofuel kilns.

5.1 Switching fuels

In exploring the changing patterns of energy use in the household, researchers have traditionally turned to the model of the "energy ladder" of Figure 6, whereby different energy currencies represent the different rungs of the ladder. At the bottom of the ladder are the least efficient, most polluting fuels. As a household gains socioeconomic status, it ascends the ladder to cleaner and more efficient energy currencies. The ladder model divides energy use patterns into three stages of fuel choice.

In the first and lowest stage, households depend solely upon solid biomass, deriving energy from the combustion of firewood and animal wastes. In the intermediate stage, households shift towards fuels that burn more efficiently, but still have notable emissions, including charcoal from biomass resources and fossil kerosene and coal. In the most advanced stage, households transition to a dependence upon the cleanest energy currencies, usually liquefied petroleum gas (LPG), electricity, or biofuels.

The crux of this model is that it implies perfect substitution of one fuel for another; households do not mix fuels but instead choose only the fuel that best fits their socioeconomic position. As income increases, one would expect households to abandon the lower tier, inefficient fuels completely in favour of the higher tier fuels that they can afford. It is thus implicit in this model that income has a uniquely important role in determining a household's fuel choice (Schlag and Zuzarte, 2008).

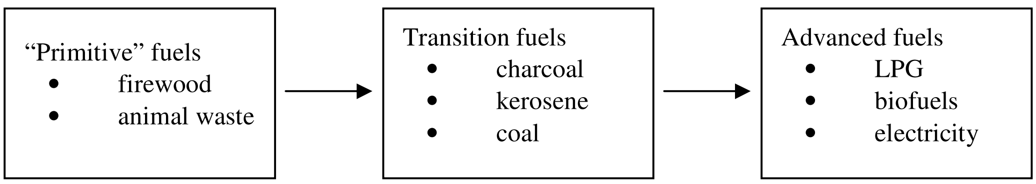


Figure 6: Schematic representation of the fuel ladder.

However, empirical data have shown that fuel substitution is often not perfect and that households use multiple fuels at one time. Recently, many researchers have supplanted this model of changing energy use patterns with what has become known as the "fuel-stacking" model proposed by Masera et al. (2000). This model rejects the linear simplification of the traditional fuel ladder, suggesting that households do not wholly abandon inefficient fuels in favour of efficient ones. Rather, modern fuels are integrated slowly into energy use patterns, resulting in the use of multiple cooking fuels simultaneously. This model is supported by the empirical data presented by Masera et al. (2000) and has been confirmed by further studies of the dynamics of fuel switching (IEA, 2002; Pachauri and Spreng, 2003). The intricacies of fuel switching in the developing world suggest that there are many factors at play besides income in determining fuel choice. Social, economic, and technological barriers prevent the linear progression towards clean cooking fuels put forth by the energy ladder. More specifically factors such as fuel availability, affordability and cultural norms and cooking practise all impact on fuel/stove adoption and continued use.

The diversity of fuels used in household cooking in Sub-Saharan Africa is representative of the complexities of the market. While a large fraction of households rely upon traditional fuels—those that the energy ladder would describe as primitive fuels, or, in the case of charcoal, transition fuels—a small percentage of households have begun using advanced fuels for cooking. The following sections describe the use of traditional biomass options for cooking in Sub-Saharan Africa.

5.2 Improved charcoal production

The process through which the charcoal is produced is called pyrolysis. Pyrolysis is the process in which the chemical structure of the wood is broken down under high temperature and in the near absence of oxygen. A wide range of technologies is available for the production of charcoal: from simple and rudimentary earth kilos to complex, large-capacity charcoal retorts. The most widely used method for charcoal production is the earth kiln. Two varieties exist, namely the earth pit kiln and the earth mound kiln. An earth pit kiln is constructed by first digging a small pit in the ground. Then the wood is placed in the pit and lit from the bottom, after which the pit is covered with green leaves or metal sheet and earth, to prevent complete burning. The earth mound kiln is an arranged pile of wood, which is lit and covered by earth to block the air flow.

A disadvantage of conventional kilns is the problem is the low average conversion efficiency. Efficiencies of conventional kilns are normally low, ranging from 10–20% on a dryweight basis; however, they largely depend on the skills and time invested by the charcoal producer and the tree species. A skilled charcoal producer who uses well-dried wood can reach efficiencies of up to 30% (Wiskerke, 2008). Further, slower growing species with a higher wood density are favored. However, in some species water is locked up so that it cannot be released by heating the wood. This negatively impacts the efficiency and quality of the charcoal. Furthermore, the age of the wood and the moisture content are influencing the quality and efficiency (Malimbwi *et al.* 2007).

Improved charcoal production technologies are largely aimed at attaining increases in the efficiency of charcoal production as well as at enhancing the quality characteristics of charcoal. Improved charcoal kilns can be broadly

classified into five categories, namely:
1. Earth kilns
2. Metal kilns
3. Brick kilns
4. Cement or masonry kilns
5. Retort kilns

The above categories are differentiated mainly by the technical sophistication and investment costs of the different kilns. The main characteristics of the each of the five categories of kilns are given in table 2.

Table 6: Main characteristics of various categories of charcoal kilns (Source UNHCS, 1993)

	Typical capacity		Yield (%)	Costs ($)	In use in
Earth kilns					
Mound	5-100	m^3	10-25	very low	Many developing countries
Casmance	variable		25-31	200	Cameroon, Ghana, Malawi and Senegal
Pit	3-30	m^3	30-35	very low	Sri Lanka, United Republic of Tanzania and other developing countries
Metal Kilns					
Mark V	300-400	kg	20-25	2000 to 5000	Uganda
Oil drum	12-15	kg	23-28	low	Kenya, the Philippines
Brick kilns					
Beehive and half-orange		9-45	25-35	150 to 500	Argentina, Brazil and Malawi
Cement or masonry kilns					
Katugo	70		25-30	8000	Uganda
Missouri	350		25-33	15000	USA and other developed countries
Retort kilns					
Cornell	1-3	tonnes	22-33	40000	Norway and other developed countries (smaller prototypes tried in Ghana and Zambia)
Lamboitte	3000-20000	tonnes /year	30-35	0,5 to 2 million	Australia, Ivory Coast, France and other developing countries.

The more complex designs are less labour intensive and include semi-automated operations. In addition, by-products in the high-cost designs are often as important, and sometimes more important than, the charcoal produced. The low-cost simpler designs are particularly suitable for developing countries where labor is abundant.

While most of the low-cost improved charcoal kilns have demonstrated high efficiencies under test conditions, none of the developed designs have attained substantive dissemination, largely because of the nature of charcoal production in many developing countries and the surprisingly high efficiency of traditional kilns under field conditions. Initially thought to be a grossly inefficient technology, a 1984/85 study in Sudan indicated that the efficiency of the traditional earth kiln is comparable with improved brick and metal portable kilns (Tebicke, 1991). A comparative study of five different kiln types showed that with the exception of the pit kiln, traditional kilns can attain similar levels of performance to improved metal kilns (World Bank, 1988), see Table 7.

Table 7: Conversion efficiencies of earth and pit kilns (Source: UNHCS, 1993)

Kiln type	Percentage recovery oven dried wood	Percentage recovery air dried wood
Casamance earth kiln	31	27
Metal channel earth kiln	29	25
Modified metal channel kiln	25	21
Earth mound kiln (control)	25	21
Pit kiln	15	13

This is also confirmed in the previous table on charcoal production technology which shows that there is no clear demarcation between the various designs in terms of yield. The critical factors appear to be operational and supervisional skill and moisture content of the utilized wood (Teplitz-Sempbitzky, 1990). The presence of a chimney that ensures optimum draught conditions also appears to be important.

A large proportion of charcoal production in developing countries is carried out as a semi-illegal part-time activity since the wood used is often illegally procured. Consequently, few charcoal makers are willing to make the investment required by improved charcoal kilns are they willing to construct in-situ kilns since they would be vulnerable to punitive official measures such as imposition of tax and seizure. Consequently, dissemination of improved charcoal techniques to the informal sector has proved to be a difficult undertaking. Improved charcoal production technologies have proved more successful in areas where production is undertaken on a commercialized basis as in the case of Malawi.

Another focus area is the transportation of charcoal. Due to the fragility of charcoal, excessive handling and transporting over long distances can increase the amount of fines to about 40 % and thus greatly reducing the value of the charcoal. Distribution in bags helps to limit the amount of fines produced in addition to providing a convenient measurable quantity for both retail and bulk sales.

In various countries in Africa projects are ongoing that are aimed at improving the efficiency of charcoal production, such as in Uganda and in Malawi (Worldbank, 2009).

5.3 Improved stoves

5.3.1 Drivers for stove design:

Different types and qualities of improved fuelwood cooking stoves are available; from relative inefficient (20%), constructed from clay and grass at zero costs, but having a short lifespan, to more efficient (30%), made from bricks or metal, having a long lifespan, but at a considerable investment cost. Furthermore, some types of improved stoves are portable. This is important since an advantage of the 3-stone stove is that it can be easily replaced. Several programs on improved cooking efficiency have been undertaken by the Ministry of Energy and Minerals (MEM) and NGO's. However, according to the MEM, shortage of capacity to teach rural communities is hindering wide adoption of improved firewood stoves in rural areas (MEM 2003). Key drivers for improved stove design are the:

- Combustion efficiency
- Heat transfer efficiency
- Safety
- Cost
- Durability
- Local cooking Practice

In the remaining of this section a detailed overview of different improved stoves is given. Several other types of stoves have been designed, but these are currently not applied on a large scale in Africa. Examples are the BP Oorja Stove, the Philips Wood Stove and the The Siemens Bosch Protos Plant Oil Stove.

Figure 7: From left to right: the BP Oorja Stove, the Philips Wood Stove and the The Siemens Bosch Protos Plant Oil Stove.

5.3.2 The Jiko stove

The Jiko, or Kenya Ceramic Stove, is a result of research and development in the 1970 and 80's, with the design being based on a type of stove found in Thailand. Designed to burn charcoal, the stove offers improvements in efficiency, fuel consumption and emissions over that of the more traditional metal charcoal stoves or three stone fires (Walubengo, 1995).

Utilising a metal body with a ceramic liner, the stove can be manufactured by artisans at low cost from scrap metal and other locally available materials. For users, the combination of low cost and suitability for both existing cooking practices and available fuels has made this stove a popular choice in many urban households. Given the 'low tech' design the stove is suitable for manufacture by semi skilled metal workers and potters and this more informal approach has enabled the wide spread dissemination of this particular type of cooking technology across sub-Saharan Africa.

Now there are 2.6 million stoves in use in Kenya alone (cumulative production now over 15 million). Of all this stoves produced, over 80% are used in urban households while only 16% are used in rural areas. This charcoal stove reduces charcoal consumption by 30% - 50%. The stove is stove is easily accessible to many majority of the urban population because of its low cost of US$ 2-3 compared to LPG of US$ 60 – 65 (Karekezi et. al., 2008).

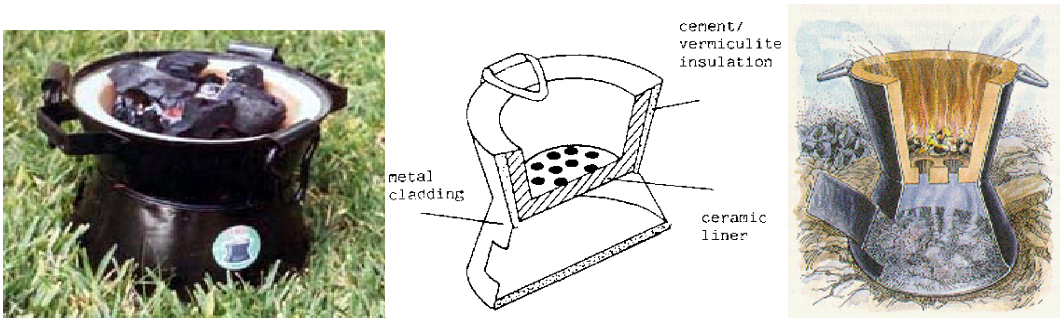


Figure 8: The Kenya Ceramic Jiko stove

5.3.3 Kuni Mbili

The Kuni Mbili firewood stove has encountered several difficulties in the move from the production centers to the market for a number of reasons. Firstly, there is no monetary value attached to the firewood collected by people living in rural areas, and hence little incentive or need to reduce firewood consumption. A second reason is that the stove is a semi-finished product, and requires skilled personnel to install the stove once bought. Stove production is also limited to clay deposits areas, and once produced and transported; the price of the stove can increase so that it becomes too expensive for rural people to afford.

Figure 9:The Kuni Mbili firewood stove

5.3.4 The Rocket Stove

The rocket stove operates on about half as much fuel, and produces substantially less smoke. Furthermore, the design of the stove requires small diameter lengths of wood, which can generally be satisfied with small branches. As such, sufficient fuel for cooking tasks can be gathered in less time, without the benefit of tools. Key advantages of the rocket stove compared to three-stone stoves are:

- Reduced of indoor air pollution, because of the chimney (although there are also models without a chimneys)
- Increased efficiency, rocket stove operates on about half as much fuel as three-stone stoves.
- Increased safety, because the rocket stove is closed on all sides, which reduces the risks for children.

Figure 10:The rocket stove

Box 4: Improved Woodfuel Stoves in Kenya

The Women and Energy project of the Ministry of Energy in Kenya initially spearheaded the production and dissemination of the Upesi stove (a one-pot improved ceramic stove that is cleaner than the traditional fire place). The German Technical Cooperation (GTZ) funded the project. The project had the overall objective of improving the living conditions of Kenya's rural population by reducing fuel wood requirements and improving fuel wood availability (Muriithi, 1995). The Upesi stove, developed by ITDG with its partners in East Africa, is made of clay and fired in a kiln. The design allows it to burn agricultural residues as well as wood, such as waste from sugar cane.

The Upesi stove benefits poor people in several ways:

- It can halve the amount of fuel wood needed by a household. This reduces drudgery and improves the sustainability of fuel wood resources.
- It provides employment. About 10 000 stoves per year are made and sold in West Kenya alone.
- It alleviates household smoke. ITDG has also introduced a new design of kiln which has substantially reduced the fuel needed to make the stoves and the scrap levels from stoves cracking during firing.

Maendeleo/Upesi stove linersmade of clay (Image:Sarah Watson, PACE)

However, with time and with more people using the Upesi stove, the question of continued and sustainable production of the stove has arisen. The continued production of improved stoves by the women's groups in West Kenya will be affected by the following factors:

- Quality of the stoves
- Availability of raw materials
- The mode of acquisition of the mould
- The ability of the women to buy or maintain a kiln
- The demand from customers/users for the different Upesi stoves
- The sustainability of marketing.

Improved cookstoves, for instance, are designed to reduce heat loss, decrease indoor air pollution, increase combustion efficiency and attain a higher heat transfer (Masera et al, 2000). In Kenya, improved cook stoves would enable an average household to save an approximate 65 Kg of charcoal per year compared to if they were using the traditional cook stoves while in Rwanda, an average household would save an approximate 84 Kg per year (World Bank, 2003).

Despite the fact that the Maendeleo liner stove has been promoted in Kenya for nearly twenty years and has recently been produced on a more commercial basis, the stove has remained at a low level of use within rural communities- only 4% of the population is using this stove. The provision of an energy saving stove to the majority of the population is one of the major objectives of GTZ.

The rocket mud stove

As a result of this concern, GTZ PSDA has introduced the rocket mud stove into Kenya, which has an even higher efficiency, to provide a choice between technologies to the consumers.

Following the success of the rocket mud stove in Uganda, where 100 000 stoves were built in only one year, it was decided to introduce the same stove to Kenya.
The rocket mud stove is a wood-burning stove, which is available as a mobile unit or can be fixed in the kitchen by a trained stove installer. The stove is designed for household use and is suitable for both large and small families.

Advantages of the rocket mud stove:

- Easy to build using locally available materials
- The rocket mud stove is clean burning and together with the chimney, significantly reduces the amount of smoke produced.
- The stove gives a potential 50-70% saving on firewood.

The decision to introduce the rocket mud stove in Kenya was based on the reasoning that since the Maendeleo liner is produced in areas near clay deposits, the cost of the Maendeleo stove can increase significantly once it is transported from the production site to the market.

One can also sit while cooking on the rocket stove. Photo: A. Ingwe

Recent evaluations show a positive uptake of the stove by the Kenya community of Kisii, although there are a few technical problems that require attention in order to provide the community with a more efficient stove that will last longer. The improved firewood stoves have been designed in order to burn firewood more effectively. This has been achieved by use of a rocket elbow combustion chamber fitted with a firewood shelf. Thermal insulation has been built around the combustion chamber and hot flue gas passage.

Advantages of Improved Firewood Stoves

- Firewood fuel savings
- Almost smokeless operation
- Easy to operate
- Affordable
- Safe to use
- Environmentally friendly

Source: M. Hoffmann, ESD

5.3.5 Vegetable oils – Jatropha

The Jatropha plant is a small hedge often planted by farmers in rural villages as a means of protecting crops, preventing erosion, and demarcating property lines. Originating in Central America, the plant is now found in large areas of southern and eastern Africa. The oil extracted from the seeds of the Jatropha plant has a wide range of possible applications; besides its potential as a cooking fuel, it can be used in soap production or for certain medicinal purposes.

Because of the benefits derived from both the Jatropha plant and its oil, Reinhard Henning (2004a) has put forth a model for rural sustainable development termed the “Jatropha System,” in which rural communities would actively cultivate the plant for the multiple uses described above. Although there are clear benefits for rural development, current technology for plant oil stoves does not limit emissions enough to make Jatropha an attractive alternative. Emissions of most pollutants are currently on the same order of magnitude as for woodfuel stoves (Mühlbauer et al., 1998); however, with improved stove technology, it is possible to reduce emissions. With such improvements, Jatropha oil could be an attractive alternative to traditional fuels.

5.3.6 Ethanol and gelfuels

Several countries in Africa are currently producing ethanol at significant scales, including Malawi, Zimbabwe, Ethiopia, and Kenya. The ethanol produced in these distilleries is mainly used as an additive in transportation fuels. However, as the industry continues to expand, ethanol offers the prospect of being able to meet household needs for cooking. Ethanol is produced by fermenting the sugars in various biomass feedstocks; it can also be produced from starches if they are first converted into sugars. The resulting mixture is then distilled to yield a high concentration of ethanol. There are a wide variety of crops that can be used as feedstocks for ethanol production, including crops such as sugarcane, cassava, sweet sorghum, maize, and wheat. The ideal feedstock for the production of ethanol is dependent upon regional climate and soil conditions, the crop's annual cycles, and available technology.

Ethanol can be burned directly in specialized stoves, though further conversion to gelfuel is a simple process that offers notable advantages. Specifically, where liquid ethanol has been used as a cooking fuel, a high number of burns have been reported. Brazil, which has been experimenting with household ethanol use, prohibited its use in liquid form for this reason and began marketing gelfuel instead (Bizzo et al., 2004). The gelfuel has a much higher viscosity than ethanol, making it easier to handle and a safe alternative.

Box 5 Cooking with ethanol gelfuels in South Africa, Zimbabwe, Malawi and Ethiopia

Despite the fact that ethanol is not yet widely available in Sub-Saharan Africa, there have been several notable projects that have attempted to introduce it to specified communities. The Millennium Gelfuel Initiative (MGI), which began in 2000 as a public-private partnership, has had some success marketing gelfuel; having demonstrated the household acceptability of gelfuels, it has established production facilities in South Africa, Zimbabwe, and Malawi and has plans to expand to other African nations (Utria, 2004). Another independent effort in Malawi led by D&S Gelfuel Ltd. in partnership with the Government of Malawi reported a wide acceptance of ethanol gelfuel in urban areas (Wynne-Jones, 2003). Project Gaia has led an experimental effort in Ethiopia, installing ethanol stoves in 850 households in Addis Ababa; the results of this project are still being evaluated.

Source: Lambe, 2006.

Because of the large output of ethanol distilleries, the fuel is well suited to meeting the energy needs of urban population; however, there has been a discussion of implementing ethanol production on a smaller scale in rural communities with micro distilleries. A recent proposal (Grassi et al., 2004) offered a model on which such a system could operate using sweet sorghum as the feedstock; the heat for the production of ethanol would be supplied by a cogeneration unit powered by biomass fuel pellets such that production of ethanol would be sustainable. Though such a system has not yet been implemented, it offers the prospect of providing clean and renewable cooking fuels to rural communities.

5.3.7 Carbon impacts

Biogas and ethanol offer the greatest potential for the reduction in carbon output, as both can be burned close to completion and produced sustainably. Assuming sustainable production, carbon output due to the use of biogas in household cooking would be on the order of one hundred times less than woodfuels when used unsustainably (Smith et al., 2000a). This is because the k-factor is so low that almost all of the carbon is released as carbon dioxide, emissions that are offset by carbon uptake due to the sustainable production of fuel.

Because ethanol has not yet reached the market, little work has been done to quantify its carbon output. However, one study conducted by the Biomass Technology Group as part of the Millennium Gelfuel Initiative (MGI) confirmed that ethanol gelfuel has the lowest carbon dioxide output per unit of useful energy of any of the clean cooking fuels (Utria, 2004). Because of its low k-factor and high combustion efficiency, the use of ethanol would likely decrease carbon emissions by a significant fraction if produced efficiently and sustainably.

5.3.8 Indoor Air Pollution

If the patterns of energy use for household cooking do not change, it is estimated that diseases attributable to indoor air pollution will cause 9.8 million premature deaths by 2030 (Bailis et al., 2005). However, the same study predicts that a transition to advanced cooking fuels could delay between 1.3 million and 3.7 million of these deaths, depending upon the rate at which the transition to clean fuels occurs. Because of their disproportionate exposure, many of the lives saved would be those of women and children. Such health-related improvements are highly prioritized in the MDGs, which include a target of a two-thirds reduction in child mortality between 1990 and 2015 (UN, 2003). At the same time, the issue of improving indoor air quality has important implications for gender equality, another subject addressed in the Millennium Development Goals. Because the task of household cooking is almost exclusively borne by women, they are often at the greatest risk for the contraction of diseases related to indoor air pollution. Thus, fuel switching offers women the opportunity for improved health—and with it, a chance to work towards development goals.

5.3.9 Socioeconomic impacts of traditional biomass

Time spent collecting firewood represents a significant opportunity cost for women and has perpetuated gender inequality in the developing world. Because many women in rural communities must spend a significant portion of their days collecting firewood, they sacrifice valuable opportunities for their advancement through education or income-generating activities. As a result, literacy among rural women in Sub-Saharan Africa is much lower than among men.

Because clean cooking fuels would be purchased in markets, the opportunity costs associated with firewood collection are not pertinent. As a result, women stand to benefit significantly through their use in household cooking. By removing the burden of firewood collection from women, the institution of clean cooking fuels would help to close the gender gap in the developing world, allowing women to devote more time to education and income generation, both of which figure critically as indicators in the Millennium Development Goals (UN, 2003).

5.3.10 Dissemination Methods

Many developing countries have some NGOs and networks researching and disseminating improved cooking stoves but penetration has generally been small in terms of the percentage of households reached, apart from India and China, who have both had government led stove programmes and combined public, NGO and private sector efforts to develop the improved charcoal burning Kenyan Ceramic Jiko (KCJ), see the previous sections.

The scale of the Indian and Chinese improved stove programmes have provided important lessons for future biomass market initiatives. India's programme (National Programme for Improved Chulas, 1983-2000) was 'target-orientated', central Government directed, heavily subsidised, and products were developed with minimal participation from the main consumers. Producers were paid 50% of their costs so were not consumer led, and the market was stifled as private entrepreneurs with their own products could not enter the subsidised market. The results were that uptake was limited, products were not replaced, and once subsidies stopped the producers also stopped making stoves.

China's National Improved Stoves Programme (NISP) took a more consumer focused, demand led approach with minimum subsidies and participation from consumers and institutions. The result was 130 million stoves disseminated with a follow up programme of support to manufacturers and energy service companies. The products have been accepted, maintained and replaced and the stoves market is now completely commercial in China.

In the past in other countries the focus of the stoves programmes has been on training the users to build their own stoves. However, while this has in some cases resulted in localized economic and social benefits, these approaches are not going to reach the existing millions of biomass stove users who are still using open fires or inefficient stoves. The lessons learnt and trends point towards a commercial, demand led approach and there appears to be considerable markets for improved biomass-burning products and fuels for companies in the SADC, India, Bangladesh, Vietnam, Pakistan and Indonesia with potential outreach of hundreds of millions.

While avoiding direct subsidies, a number of organisations provide training, outreach services, publicity, and logistical support for the local commercial industry. This 'soft' subsidy can be particularly effective in facilitating the development and acceptance of a new technology without introducing the price distortions that can be associated with some forms of subsidy.

The lessons for international involvement that can be drawn from the KCJ case include:

- Support for research both within developing nations and for research collaborations between developing nations can lead to significant innovations in the performance and commercialization of what had been regarded by many as a simple and mature technology.
- Extended, stable, programme support is invaluable while short-lived, episodic funding can lead to waste and inefficiency. There are significant technical, social, cultural and economic questions that must be addressed even for technologies that may appear simple.
- Support for stove programmes need not take the form of direct subsidies. Partnerships between institutional groups, including NGOs and international organisations, involved in R&D, promotion, and training can support commercial producers and sellers if the mechanisms for feedback and cooperation are planned and developed.

6 Electricity and heat production

6.1 Digestion and biogas production

6.1.1 Biogas

Biogas technology, at its simplest form, involves the use of digesters that are vessels in which animal and/or human waste and other bio-degradables including dedicated energy crops such as wheatgrass are broken down (digested) by bacteria, in the absence of oxygen. The process is thus referred to as anaerobic digestion (AD).

These digesters are often below ground, while the AD process produces both a methane-rich gas (biogas) that can be used as a fuel for cooking, heating, lighting, and power generation (for example via an internal combustion engine), and a nutrient rich liquid fertiliser, referred to as bioslurry. Therefore, biogas is a safe and sustainable source of energy, but the digestion process, as a positive externality, produces the bioslurry. Combine this energy and fertilizer-producing technology with water harvesting techniques, and it is possible to run food gardens even in some of the most adverse climatic conditions. When technically and financially viable, biogas is a key to unlock a comprehensive rural economic development strategy that can contribute significantly to improved and sustainable livelihoods.

For Africa, there are three primary focus areas for the introduction and hence wider dissemination of the technology. Households are a key opportunity area, where those homes with access to some manures and water (even used water), and with an average ambient temperature greater than 15 ^{O}C are technically suitable for use of the technology. Livestock farmers, most particularly cattle, chicken and pig farmers, and at any scale can also enjoy sustainable energy production, improved waste management and improved on-site fertiliser production. The two preceding focal areas are essentially rural applications; the third area, that of wastewater treatment applies to both rural and urban areas. The wastewater can include sewage, residues from the food and beverage industry, and

One of the most important advantages of biogas is its feasibility in rural areas, where it offers the prospect of sustainable development projects. The scale of the digesters can vary to suit the energy needs of a household or small community, and the only input (organic waste) is readily available in rural areas. Modern biogas digesters designed to produce energy for a household can be operated on the waste produced by four humans or one to two cows. Several nations have made efforts to introduce digesters to rural areas, but biogas remains an untapped energy resource. In Tanzania, which had an ambitious programme to disseminate biogas technology in the 1980s, only 200 digesters were operating as of 1991 (Rutamu, 1999). However, biogas has seen greater success in China and India, which have approximately 11 million and 2.9 million digesters, respectively (Bizzo et al., 2004); the widespread use of biogas in these nations offers promising evidence that it is a viable energy resource for household cooking.

What makes biogas an attractive option is the fact that this technology can provide solutions to a variety of problems simultaneously: In general it has been proven that the energy aspect alone does not justify the cost for biogas technology. But the essential benefits of biogas plants are not manifested in individual cost-efficiency calculation. The overall objective, to which biogas technology contributes, is environmental protection that includes energy-related objectives (decrease of greenhouse gas emissions as well as deforestation) and the improvement of livelihoods of biogas users. With a high total energy efficiency in combustion near 60% (Smith et al., 2000a), biogas is well suited for use in household cooking.

Properly designed and installed biogas systems will have a long lifetime (in excess of twenty years) and can yield a whole range of benefits for their users, the society and the environment in general:

- production of energy (heat, light, electricity)
- transformation of organic waste into high quality fertilizer
- improvement of hygienic conditions through reduction of pathogens, worm eggs and flies
- reduction of unpleasant odours
- reduction of workload, mainly for women, in firewood collection and cooking (household application)
- environmental advantages through protection of soil, water, air and woody vegetation
- household-level benefits through energy and fertilizer substitution, additional income sources and increasing yields of animal husbandry and agriculture
- macro-economical or societal benefits through decentralized energy generation, import substitution and environmental protection
- biogas technology can substantially contribute to conservation and development, if the concrete conditions are favorable

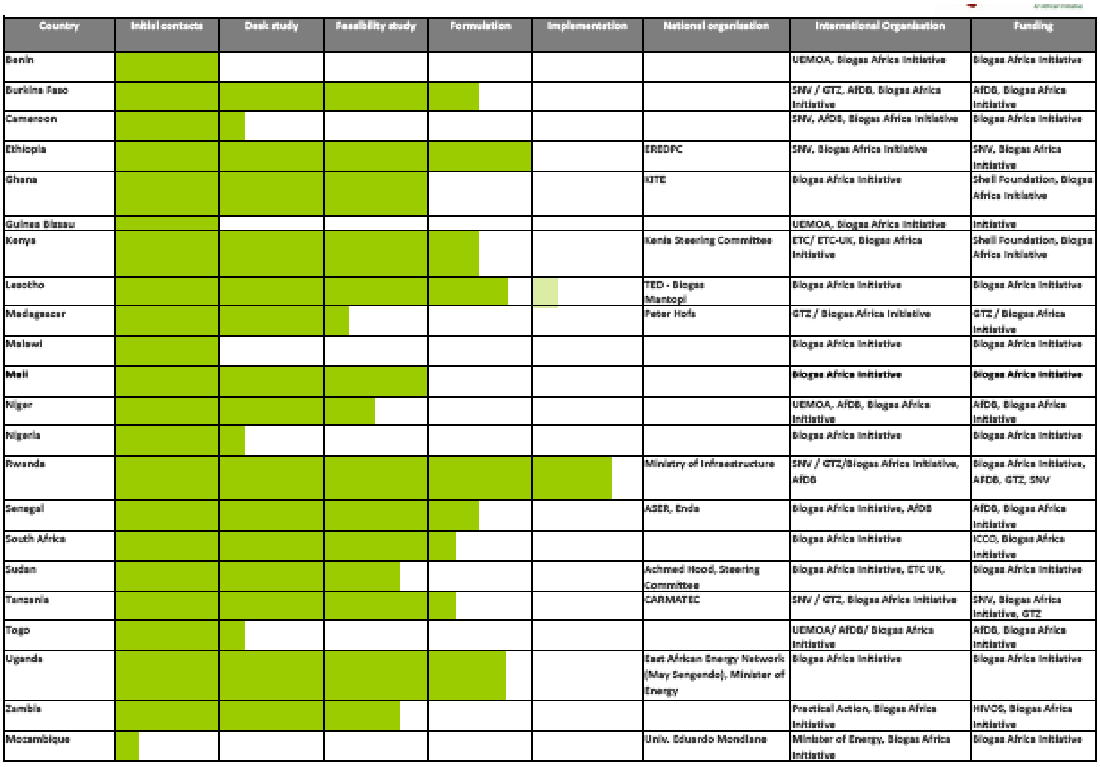
Table 8: Advantages of biogas for a household

Advantage	Quantification
Reduction in workload	Average of 2.5 hours per day
Saving in firewood	1,800 kg per year
Saving in crop waste	600 kg per year
Saving in dried manure	250 kg per year
Saving in fossil fuel (kerosene)	45 litres per year
Reduction in CO_2 emissions	2 - 4.5 tons per year
Increased agricultural yields	Up to 40%

Even though biogas systems function under a variety of climatic conditions, widespread acceptance and dissemination of biogas technology has not yet materialized in many countries. One main reason is the required high investment capital. Another common reason for failure is the sometimes unrealistically high expectations of potential users; biogas technology cannot solve every problem of a farm, a village or a big animal production unit. The limitations of biogas technology should be clearly spelt out to the potential customers!

An obvious obstacle to the large-scale introduction of biogas technology is the fact that the majority of rural populations often cannot afford the cost of investment for a biogas plant. The installation of a few biogas plants often can only be afforded by better-off farmers. High up-front investment costs for even small biogas units are still not affordable for poor households.

The vast African potential household market for biogas digesters has been recognised, and addressed through a new continent-wide programme namely Biogas for Better Life (www.biogasafrica.org). This programme aims at 2 million household digesters in over twenty African countries, undertaken through a programmatic approach that co-ordinates funding, capacity building, studies, and implemented through a commercial mechanism via local-level enterprises. The following diagram outlines the status of the progress in different countries as of May 2008.



Country	Initial contacts	Desk study	Feasibility study	Formulation	Implementation	National organisation	International Organisation	Funding
Benin							UEMOA, Biogas Africa Initiative	Biogas Africa Initiative
Burkina Faso							SNV / GTZ, AfDB, Biogas Africa Initiative	AfDB, Biogas Africa Initiative
Cameroon							SNV, AfDB, Biogas Africa Initiative	Biogas Africa Initiative
Ethiopia						EREDPC	SNV, Biogas Africa Initiative	SNV, Biogas Africa Initiative
Ghana						KITE	Biogas Africa Initiative	Shell Foundation, Biogas Africa Initiative
Guinea Bissau							UEMOA, Biogas Africa Initiative	Initiative
Kenya						Kenia Steering Committee	ETC/ ETC-UK, Biogas Africa Initiative	Shell Foundation, Biogas Africa Initiative
Lesotho						TED - Biogas Mantopi	Biogas Africa Initiative	Biogas Africa Initiative
Madagascar						Peter Hofs	GTZ / Biogas Africa Initiative	GTZ / Biogas Africa Initiative
Malawi							Biogas Africa Initiative	Biogas Africa Initiative
Mali							Biogas Africa Initiative	Biogas Africa Initiative
Niger							UEMOA, AfDB, Biogas Africa Initiative	AfDB, Biogas Africa Initiative
Nigeria							Biogas Africa Initiative	Biogas Africa Initiative
Rwanda						Ministry of Infrastructure	SNV / GTZ/Biogas Africa Initiative, AfDB	Biogas Africa Initiative, AFDB, GTZ, SNV
Senegal						ASER, Enda	Biogas Africa Initiative, AfDB	AfDB, Biogas Africa Initiative
South Africa							Biogas Africa Initiative	ICCO, Biogas Africa Initiative
Sudan						Achmed Hood, Steering Committee	Biogas Africa Initiative, ETC UK,	Biogas Africa Initiative
Tanzania						CARMATEC	SNV / GTZ, Biogas Africa Initiative	SNV, Biogas Africa Initiative, GTZ
Togo							UEMOA/ AfDB/ Biogas Africa Initiative	AfDB, Biogas Africa Initiative
Uganda						East African Energy Network (May Sengendo), Minister of Energy	Biogas Africa Initiative	Biogas Africa Initiative
Zambia							Practical Action, Biogas Africa Initiative	HIVOS, Biogas Africa Initiative
Mocambique						Univ. Eduardo Mondlane	Minister of Energy, Biogas Africa Initiative	Biogas Africa Initiative

Figure 11: Progress of country programmes – Biogas for Life, an African Initiative. (Source: AfDB, 2008).

The technical viability of biogas technology has been generally proven in field test and projects; the economic viability of biogas digesters is under discussion and is not viable for some contexts. The establishing of an efficient and sustainable dissemination structure continues to remain the key problem of numerous biogas projects. The viability and reliability of biogas projects usually depend on a number of factors, such as:

- Quantity of available biomass/animal waste: Sufficient biomass/manure on a continuous basis should be available to maintain installed biogas units. Project experiences show that if more biogas units were installed than biomass manure has been available, unreliable and disrupted energy services were a consequence.
- Location of biogas project: if a project combines the provision of energy services with income-generation, such as the production and selling of manure as fertilizer, the local market situation plays a role, as it is critical to have a sustainable local demand for fertilizers and a critical mass of users. Users, such as farmers, will loose interest in using biogas units if there is no financial benefit associated with producing and marketing manure.
- Ownership issue: Users of biogas units should, if possible, make a financial contribution to the installation of biogas units, to develop an ownership perception of the energy provider.

- Combined biogas units: Experience shows that larger institutional biogas units run by institutions such as schools or hospitals are more financially viable than small-scale biogas digesters, but the sustainability is often questionable given the complexities in ownership, operation and maintenance.

Figure 12: Construction of a 20m^3 biogas digester for processing sewage wastewater, food scraps and chicken litter (Source: AGAMA Biogas, 2007)

Figure 13: 4m^3 single household digester (in background), anaerobic baffled reactor (midground) and gravel filter (foreground) producing Water Affairs compliant water quality while processing sewage and food scraps to produce thermal energy for cooking (Source: AGAMA Biogas, 2007)

Figure 14: Construction shot of household digester for processing cattle manure, biogas produced fully offsetting fuel wood use and providing much needed fertiliser in the form of bioslurry to the garden (Source: AGAMA Energy, 2008).

6.2 Combustion technologies for heat and electricity

6.2.1 Institutional stoves

Institutional stoves are stoves used in big institutions like; schools, hospitals, canteens, barracks and clinics among others. Institutional cookstoves are classified into three categories namely improved, semi-improved and traditional. Improved imply the biomass efficient cookstoves, with lining made of insulating bricks that minimize heat loss; semi-improved are those that are partially enclosed with mud or brick lining thus using slightly less firewood compared with the traditional 3-stone open-fire cookstove (UNDP/GOK, 2007). Lab tests indicate that the institutional barrel stove in Gulu Uganda could save 73% of the fuel used by the open fire. According to Scott 2004, the MangiMangi stove in Mozambique has a number of advantages over the open fire;

- Efficient: uses 80% less wood than their open fire
- Fast: boils 40L of water in 30min with 2kg of wood
- Clean: produces almost no visible smoke
- Inexpensive (approx US$150) and very low maintenance.

Table 9. Classification of Institutional cookstoves in Kenya

Class	Cost (range)	Description of stove features
Improved	• Relatively expensive depending on cost of materials, size of the cookstove, and the manufacturer. On average it can range from Kshs 20, 000.to 250,000	• Lining made of insulating bricks that minimize heat loss, with stainless steel outer casing. • Very efficient in wood consumption (5070%) • Fitted with chimneys that release smoke to the atmosphere • Complete combustion of fuelwood thus minimum emission of GHGs to the environment • Some are fixed to the ground while others are portable • Easy and safe to use
Semi-improved	• Locally made and the cost depends on the cost of materials and service charge at different locations in the country	• they are commonly fixed on the ground • Partially enclosed, normally made of either metal, mud or bricks • some have chimneys which are partly efficient in releasing smoke to the atmosphere • uses slightly less wood compared with traditional cookstoves
Traditional	• Usually, no costs incurred because the stones are locally collected.	• Commonly threestone open fires • Some are made of bricks enough to fit the sufuria but are not enclosed.

In Kenya, 58% of institutions use improved stoves 13% use semi-improved, whereas 29% used traditional cookstoves. In Kenya, institutions in the urban areas have the highest adoption of improved cookstoves compared to rural areas because are likely to face fuelwood supply problems and high costs due to lack of fuelwood from surrounding areas, making it necessary for them to invest in fuel-saving stoves. For instance, a tonne of firewood in humid areas, where Nairobi and Central province fall, cost between Kshs. 1000 to1500 whereas in semi-arid areas such as parts of Eastern and Rift Valley province range between Kshs. 500 to 1,100 (UNDP/GOK, 2007).

Table 10: Percentage adoption of improved stoves by province in Kenya (Source: UNDP/GOK, 2007)

Province	Percentage improved stoves
Eastern	58
Rift Valley	58
Coast	39
Nairobi	63
Central	87
Nyanza	63
Western	58

What should be considered before starting the introduction of improved institutional and/or industrial stoves?

- Need to understand the position and experiences of the target group or "customer", both external and internal factors.
- Know the real situation with regard to fuel supply, raw material supply, labour, ownership, decision making process, etc.
- Different and opposing priorities: management, labour, male-female.
- Seasonal influences in stove use as well as fuel supply should fit in with expectations e.g. costs versus benefits should fit in with financial rather than economic real life.
- Approach should be step by step but with direct involvement of target group (opposing priorities) and where possible with increasing cost recovery.
- Advisory services – expensive and therefore a need to look for integration with other services/credit, taxation back up, maintenance services, standardization, commercialization.
- Transfer of competence versus transfer of hardware
- Know the scope of the program: stoves or stoves plus other components; may also have to consider fuel supply rather than only hardware.
- It takes time for entrepreneurs to make decisions about their technology investments
- Know that reliability is the most important factor for industries and institutions as an investment in their enterprise.
- A factor that should be considered when applying the technology is who accrues the economic benefits. Those who directly operate the stoves may not experience direct economic benefit and thus have less inclination towards proper use as compared to the institution or industry manager who may directly benefit from maximal usage.

According to Biomass Energy Services and Technology Pty. Ltd, (BEST) details of the design procedure for institutional stoves include;

- The first step is determining the customer's requirements, including needs, availability of local resources, safety and health, comfort and cost.
- The second step is a determination of whether an existing stove should be modified (usually the more successful option) or an entirely new one designed. Modifications can include: sinking of pots into stove; enclosure of the firebox; elimination of cracking and gaps; insulation of walls; raising or lowering of the pot over the flame; minimising the distance between the flue passage way and the pot walls; and adjusting the height and diameter of the chimney.
- Step 3 involves determining the type of material for construction. This will depend on availability, capital cost, method of manufacture, and desired lifetime. A discussion of relative merits is given.
- In step 4 the critical dimensions of a new stove design are calculated. These include: the grate size; the height of the combustion chamber; the

size of primary and secondary air; holes; and the width of the gap between the pot and the wall of the stove.

Commercialization is one strategy that has been employed to facilitate the distribution of efficient stoves. This includes production, dissemination, monitoring and financing. However there are many barriers to institutions and industry in purchasing new stoves. The biggest is lack of cash. Cooks and operatives may be unwilling to change. Existing kitchens and works may not be suitable.

6.2.2 Cogeneration Technology

Cogeneration involves generation of high pressure steam from pressurized water, with the resulting steam expanding to drive a turbo-generator, and then condensing back to water for partial or full recycling to the boiler. A heat exchanger is used to recover heat from flue gases to preheat combustion air, and a deaerator is used to remove dissolved oxygen from water before it enters the boiler. An electrostatic precipitator is installed to remove the particulate matter in the boiler flue gases while a dry ash extraction system is used to remove the ash generated from the combustion. This is an improvement from the current wet ash system which results in some of the carbon and other compounds in the ash being discharged into the Nzoia River. The ash is usually used for soil condition and pH correction in the plantations. The technology used is safe, environmentally friendly and proven. The successful completion of this project activity is likely to contribute to the adoption of similar cogeneration technologies by firms in the sugar and other industry sectors in Kenya. Currently, there is no sugar company in Kenya or East Africa that is using the high steam pressure technology to generate electricity for export to the grid.

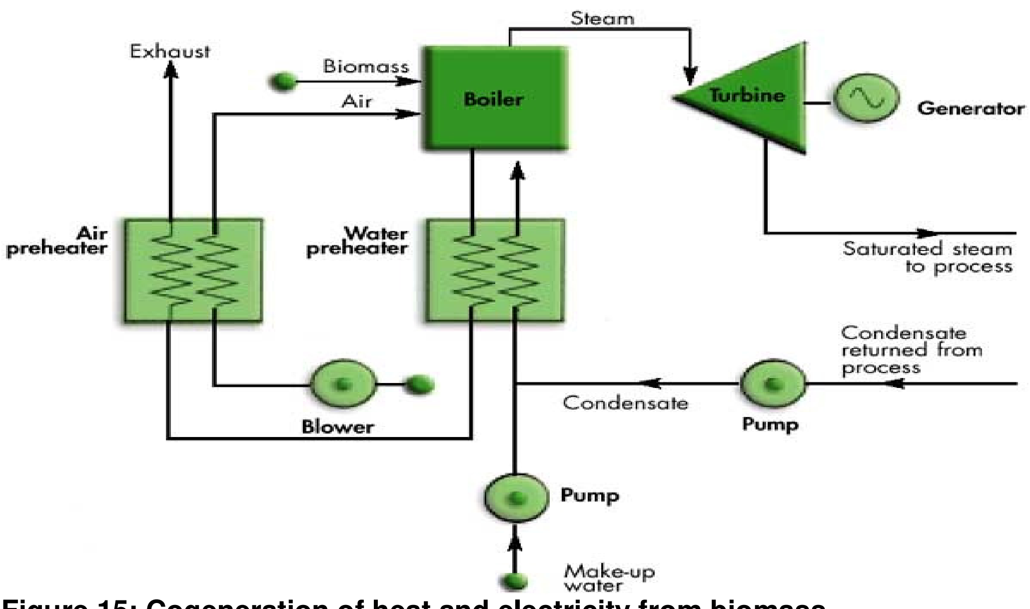


Figure 15: Cogeneration of heat and electricity from biomass

For example, the cogeneration project activity in Mumias Kenya is based on conventional steam power cycle involving direct combustion of biomass (bagasse) in a boiler to raise steam, which is then expanded through a turbine to generate electricity. The plant comprises of a new 150 t/hr at 87 barg and 525 0C in combination with the existing 110 t/hr low pressure (21 barg) steam boiler. The new configuration consists of 4 turbines (one new double extraction-condensing turbine of 25 MW in combination with the existing 7 MW and two 2.5 MW back pressure turbines). The steam extracted from the turbines is used in the sugar production processes.

The steam cycle plant will be located within the factory where the exhaust from the steam turbine is recovered and used for meeting industrial process steam and heat needs. The technology combines heat and power (cogeneration) systems with greater levels of energy services per unit of biomass (bagasse) consumed than systems that generate power only. For Mumias Sugar Company, steam recovery will not be of much value as the factory will not need additional steam for efficiency improvement, instead, the project is aimed at utilizing excess bagasse which is not utilized (dumped in the nucleus estate) at the moment, and boiler efficiency improvement to generate electricity which will be exported to the national electricity grid.

Box 6: Barriers and Drivers to the Mumias Cogeneration plant, Kenya

Mumias Sugar Company Limited crushed 2,400,000 tonnes of cane in 2005 and is expected to crush similar quantities in 2006 based on the quantities crushed so far and the projections for the remaining months of the year. Of the total cane crushed, existing data indicate that 37% is bagasse yield which is equivalent to 888,000 tonnes of bagasse. The same data shows that for each tonne of sugarcane crushed, 0.27 tonnes of bagasse is used to produce process energy (steam and electricity). This leaves a surplus of 240,000 tonnes of bagasse (10% of total cane crushed), and it is this amount which is transported by company trucks and dumped in the plantations to decompose with significant methane emissions. Usually the bagasse is dumped in areas where soil has been excavated for road maintenance and covered with soil or are spread in areas where sugar cane is not grown within the nucleus plantation. The project will therefore reduce GHG emissions directly from the following sources:

- Displacing grid electricity with GHG-neutral biomass electricity generation - This component of the project activity is expected to achieve GHG emission reductions of 872,863.08 t CO_2e over the 10 year period (2008-2018).
- Methane abatement through avoidance of dumping of bagasse and instead using it to generate electricity which is expected to achieve GHG emission reductions of 82,352.40 tCO_2e over the 10 year period.
- The overall GHG emission reductions expected from the project is therefore 955,215.68 tCO_2e over the period (2008-2018).

Intermittent Power - Excess electricity is sold to the grid, only when fuel available and capacity permits. Sometimes the power is used to reinforce grid during peak periods. In Kenya, only Mumias Sugar factory has the capacity for intermittent power supply though constrained by regulatory barriers. During the electricity crisis of 2000, Mumias was able to sell power, this time limited by the capacity of interconnecting transformers linking them to the grid.

Barriers facing the Mumias cogeneration plant in Kenya
a) Investment barriers,
The Mumias Sugar Company is still to a large extend is being controlled by the government and there fore there is inefficiency in terms of management. Most of the local investors and financial institutions do not have any experience in financing this kind of investment. The government currently does not have a comprehensive policy on price that Kenya Power and Lighting Company (KPLC) is to pay on power from cogeneration sources and this has made it difficult to have strict and precise projection on sales revenue and profits, this fact has deterred investors and financiers.

b) Technological barriers,
Technological barriers represent a very important issue for increasing bagasse cogeneration in Kenya. Despite the fact that Rankine-cycle is a well known technology, the cogeneration units operate with low-efficiency and are not competitive comparing to other generation options. In this way, there is a tricky issue about technology and economic value for such technology. Although this technology is well developed, the economic value for its application is not present for projects on the scale similar to the sugar mills in Kenya.
This is a new technology in the local sugar industry and therefore initially there would be inadequate trained manpower to operate it and Mumias Sugar Company will have to spend some time and resources to train personnel with right skills to operate the technology. It would also be difficult to find repair and maintenance services for the machines and even spare parts would have to be sourced from abroad at least for the first years of operation. The

c) Institutional and Political Barriers
From the sugar mill point of view, the great majority of sugar mills do not consider investment in cogeneration (for electricity sale) as a priority. The sector "even in the new political context, does not seem to have motivation to invest in a process that it sees with mistrust and no guarantees that the product will have a safe market in the future". Moreover, "the sugar mills are essentially managed by the government, which hurdles the association with external financial agents" that would allow the sector to be more competitive and diversifying its investment. From the point of view of the economic agents, the excessive level of guarantees required to finance the projects is a common barrier to achieving a financial feasibility stage. Other barriers have more to do with the lack of adequate commercial contractual agreements from the energy buyer, KPLC (i.e. bankable long-term contracts and payment guarantee mechanisms for noncredit worthy local public-sector and private customers) making it much more difficult to obtain longterm financing from a commercial bank and/or a development bank. Some other financing barriers occur simply due to prohibitively high transaction costs, which include the bureaucracy to secure the environmental license and electricity generation license.

d) Cultural Barrier
Due to the nature of the business in the sugar industry the marketing approach is narrowly focused on commodity type of transaction. Therefore, the electricity transaction based on long-term contract (Power Purchase Agreement) represents a significant breakthrough in their business model. In this case, the electricity

transaction has to represent a safe investment opportunity from both economical and social environmental perspective for convincing the sugar mills to invest in.
There are also questions regarding the managerial capacity of the companies that comprise the Kenyan sugarcane industry. Apart from MSC, the companies have in many cases demonstrated the will to undertake investments in new technologies, but without sufficient financial and entrepreneurial capacity to complete such projects.

Source: M.Hoffmann, S.Mutimba, ESD

6.2.3 Biomass Boilers

Biomass boiler system equipment is based on established technologies for solid fossil fuels, which have been adapted to cope with the properties of biomass materials. The main types of product available use the following processes:

- Direct combustion of biomass – where sufficient air is supplied to the burning fuel to ensure complete combustion.
- Two-stage systems: Stage 1 – the fuel is either gasified by reacting it with a limited amount of air (insufficient air is supplied to allow combustion, or CO2 or steam is supplied instead of air); or pyrolysed by heating in the absence of air. Both processes produce a fuel gas and solid char, and in Stage 2 both of these can be burned to release heat.

The two-stage processes were originally developed for large scale solid fuel thermal plants, but the principles also appear in some biomass boiler designs. In Kenya biomass boilers are used in coffee industries to roast the coffee seeds. They are also used in paper industries, and tea industries.

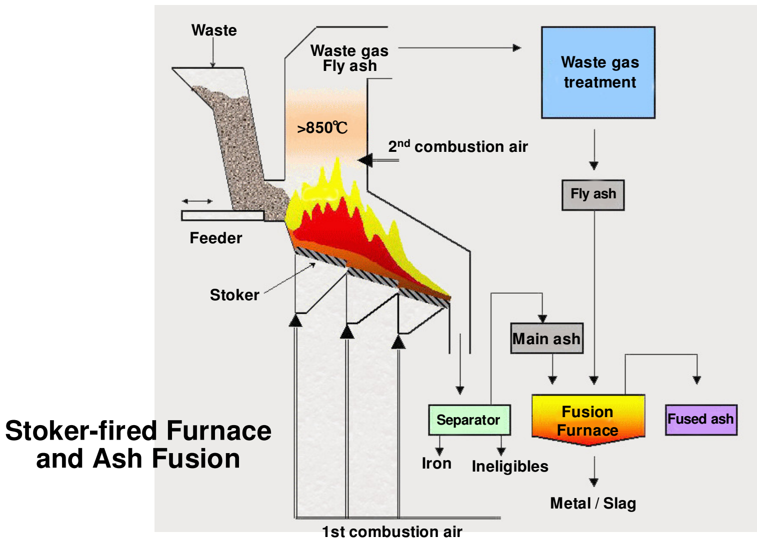


Figure 16: Biomass combustion in a stoker-fired furnace

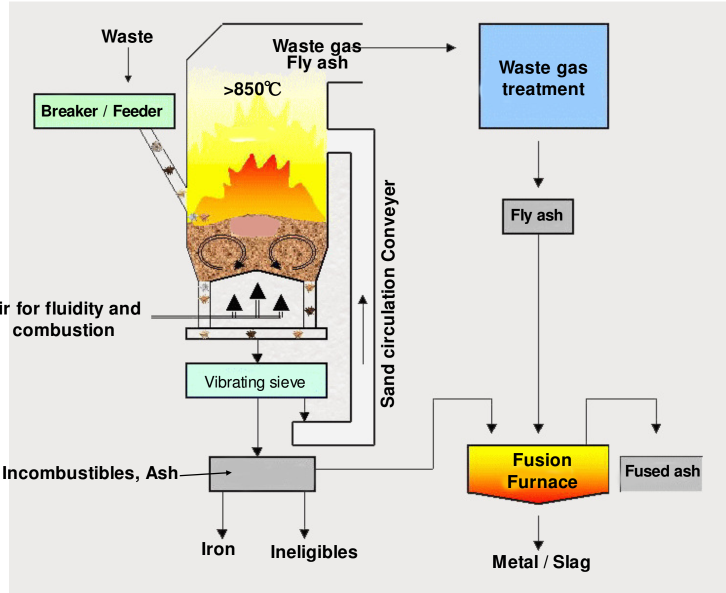


Figure 17: Biomass combustion in fluidized bed furnace

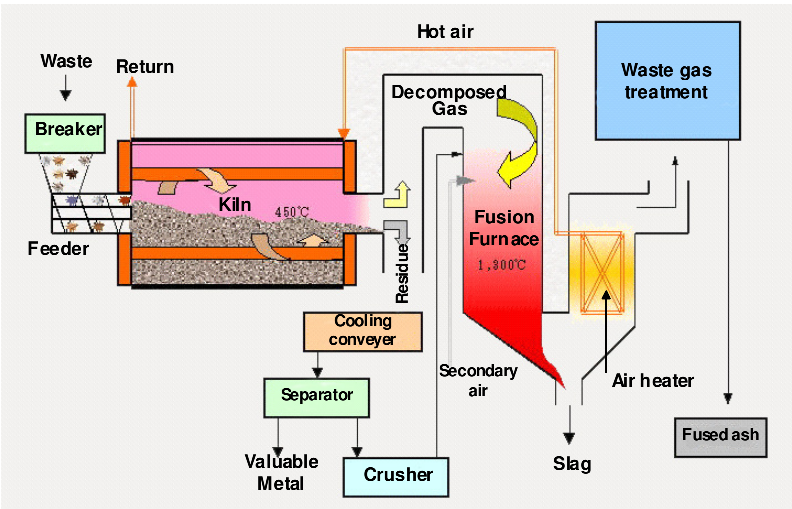


Figure 18: Biomass conversion in a rotary kiln type thermal decomposition combined with gasification

Box 7: The use of Agricultural residues for electrification in Senegal

Some industries in Senegal are autonomous electricity producers. The most important ones are the Compagnie sucrière du Sénégal (CSS; the Sugar Company of Senegal), the Société Nationale de la Commercialisation des Oléagineux du Sénégal (SONACOS[1]; the National oilseed company of Senegal), the Société de Commercialisation du Ciment (SOCOCIM Industires; cement factory), the Industries

[1] SONACOS was renamed Suneor on January 1st 2007.

Chimiques du Sénégal (ICS, the Chemical Industries of Senegal), the Ciments du Sahel (Cim-Sahel; the Cement of Sahel).

The electricity that is produced in these industries is used for internal consumption and the surplus is sold to the Société Nationale d'électricité (SENELEC, the National electricity utility). SENELEC is the single buyer of electricity in Senegal. In 2005, 0.7 GWh electricity was sold by the autoproducers to SENELEC (Système d'Information Energétique du Sénégal, 2006).

Of the companies listed above, SONACOS and CSS produce electricity from Agricultural residues. CSS is the only sugar refinery in Senegal and uses the residues of sugar cane milling (bagasse) for the production of electricity. SONACOS produces oil from peanuts, whereby the peanut shells are used to generate electricity.

The quantities of bagasse and peanut shells that are used for power generation in the Senegal are shown in the following table.

	2000	2001	2002	2003	2004	2005
Bagasse (Toe)	49.9	47.7	47.6	45.9	55.2	50.9
Peanut shells (Toe)	20.2	22.0	23.9	11.1	5.9	13.2
Electricity produced from Bagasse (Mwh)	33877	33834	34213	32829	32312	31893
Electricity produced from Peanut shells	17210	25900	34260	21600	9760	18581
Total electricity produced (Mwh)	51 087	59 734	68 473	54 429	42 072	50 474

The current production of bagasse and peanut shells used for electricity generation is around 308 and 33 thousand tons, respectively

Sources: T. Dafrallah, ENDA-TM; SIE-Sénégal, 2006

6.3 Gasification technologies

Wood, which is an abundant and important biomass feedstock is difficult to be digested but can easily be transformed in SNG through a gasification process. For this reason Gasification seems a promising real opportunity because using wood and other biomass resources such as yard, crop waste, waste and residual pulp/paper plant materials etc is not competing with food commodities production and reaches high total conversion efficiency. Municipalities as well as the agricultural industries are looking for ways to reduce the disposal costs associated with these wastes and for technologies to produce electricity and other valuable products from these waste materials. Although more advanced gasification technology is under development since more than 50 years, biomass gasification has not reached the level of commercial demonstration, but however shows a great deal of promise.

6.3.1 Main concept of Gasification process

Gasification is an energy technology that can convert low-value feedstock into high-value products, can help to reduce dependence on foreign oil and natural gas, and can provide a significant amount of clean renewable source of energy. The manufacturing process converts by the thermochemical high temperature process, biomass into synthesis gas (syngas). The syngas can be burned directly to produce electricity or further processed to manufacture liquid fuels, chemicals, substitute natural gas (SNG), or hydrogen (Figure 19).

Most of the processes use biomass feedstock injected with oxygen and steam into a high temperature pressurized reactor so that the chemical bonds of the feedstock are broken. The resulting reaction produces the syngas a mixture of H2 and CO with some small amounts of other gases and impurities. The syngas is then cleaned to remove impurities such as sulfur, mercury, particulates, and trace minerals. (Carbon dioxide can also be removed at this stage.) The H2/CO ratio is then adjusted and the clean syngas is used to make a wide range of different products such as hydrogen, liquid biofuels, chemicals, electric power.

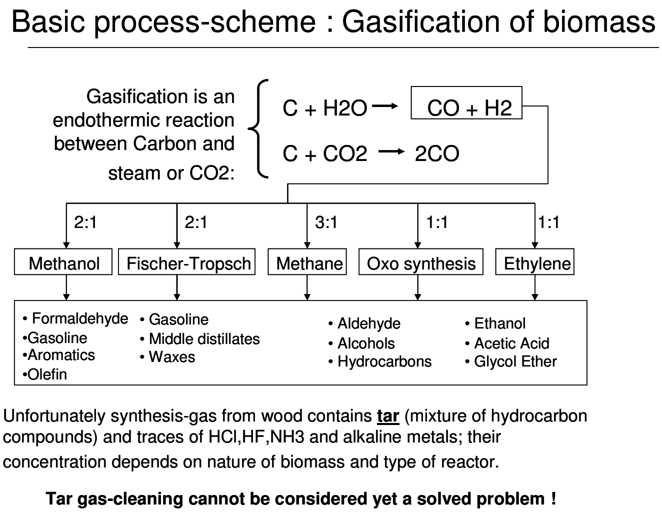


Figure 19: Gasification of Biomass and related products

6.3.2 Gasification Applications and products

Gasification is may be used to produce *synthetic natural gas* (SNG), but using a specific cathalytic "methanation" reaction, is possible to change this syngas (carbon monoxide (CO) and hydrogen (H2)) to methane (CH4). Nearly chemically identical to conventional natural gas (CH4 is the major component), the resulting gas can be used to generate electricity or heat.

Gasification is the foundation for converting biomass into *transportation fuels*. Two basic paths are employed in converting biomass to liquids via gasification. In the first, the syngas undergoes an additional process, the Fischer-Tropsch (FT) reaction, to convert it to a liquid product. In the second process, so-called Methanol to Biofuel (MTB), the syngas is first converted to methanol (a commercially used process) and the methanol is further converted to liquid biofuel (i.e. DME) by reacting it over a bed of catalysts.

The advanced *biomass-to-power* technology allows the continued use of biomass without the high level of emissions associated with conventional biomass burning technologies. This occurs because in gasification power plants the pollutants in the syngas are removed before the syngas is combusted in the turbines. In contrast, in conventional combustion technologies there is a need to capture the pollutants after the exhaust gas has passed through the boiler or steam generator.

The clean syngas can also be combusted (burned) directly without conversion in methane in gas turbines to generate electricity with very low emissions. The gas turbines used in these plants are in general derivatives gas turbines jet-engines that have been specially adapted for use with syngas for power production. These gas turbines are able to operate on syngas with high levels of hydrogen (typical 50% of H_2 in volume). Hot discharge gas from gas turbine can be circulated through heat recovery steam generator that is used to make additional power by steam turbine (combined-cycle unit).

Steam recovered from the gasification process is superheated in the HRSG (Heat Recovery Steam Generator) to increase the overall efficiency output of the steam cycle, hence the full cycle is named Integrated Gasification Combined Cycle. This IGCC combination, which includes a gasification plant, two types of turbine generators (gas and steam), and the HRSG, is clean and efficient power production system producing NO_x levels lower than 0.06lb per MMBtu (basic emission of coal power generation) and combined cycle efficiencies can exceed 65% when process steam integrated from the gasification plant is included.

Another example of the “integrated” design (in the fully integrated IGCC) is the possibility for the gas turbine to compress air to the oxygen plant. This reduces the capital cost also decreasing the amount of power required to operate the oxygen plant.

Producing more than one product at a time (co-production or “polygeneration” Figure 20), such as the co-production of electricity, steam, and chemicals (e.g., methanol or ammonia) is also possible and might improve economics.

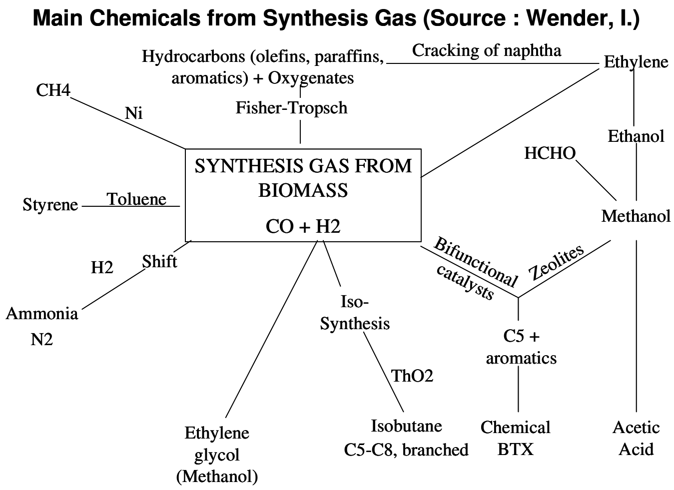


Figure 20: Main Chemicals from Synthesis Gas

6.3.3 Environmental and Economical benefits of gasification

Gasification enables the use of biomass to produce electricity with significantly reduced environmental impacts compared to traditional combustion technologies because:

- Syngas is cleaned before combustion, gasification plants produce significantly fewer quantities of noxious air pollutants such as nitrogen oxides (NO_x) and sulfur dioxide (SO2).
- Gasification enables the recovery of available energy also from low-value materials (municipal solid waste), thereby reducing both environmental impacts biodegradation and disposal costs.
- The byproducts from gasification (sulfur and ashes) are non-hazardous and are readily marketable.
- Gasification plants use significantly less water than coal combustion plants, and can be designed as zeroliquid water discharge facilities.

6.3.4 Outlook

Coal gasification for electricity production has reached commercialisation in the past 5-10 years with over 90 installations and 60 manufactures around the word. The main advantages of gasification are:

- High electrical efficiency
- Substitute of natural gas or diesel in boilers
- Distribution of power generation where power demand is low
- Substitution of gasoline/diesel in internal combustion engine.
- Gasification of biomass is not yet commercial but appears as a very promising technology, but to penetrate the market their costs have to be lowered considerably. Therefore, to stimulate large scale investment, acceptable prices of raw material, lower cost for production, lower costs for technology and process are needed.

The first successful demonstration of biomass gasification at industrial scale has been implemented at Värnamo in Sweden (test program ended in 1999). On the basis of recent feasibility study, Eon Sverige spotted 20 locations for potential plants in Sweden. However, actually Eon has still to make a full demonstration (at semi industrial scale) before commercialisation.

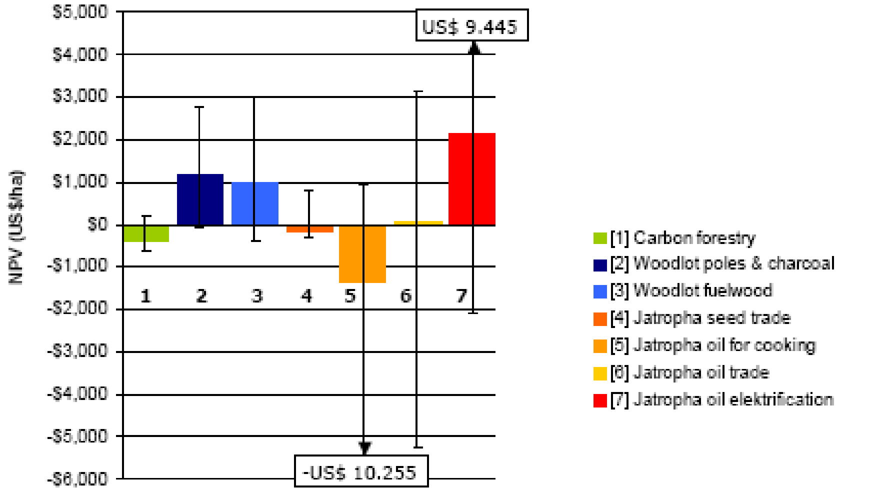
Box 8: Socioeconomics of bioenergy production in Tanzania

Wiskerke (2008) analyzed and compare the costs and benefits of three alternative sustainable biomass energy supply systems for rural households in a semi-arid region in a developing country. Thereby, the main opportunity costs and optional benefits of each system are included and an uncertainty analysis is carried out. Shinyanga region in Tanzania was chosen as a case study.

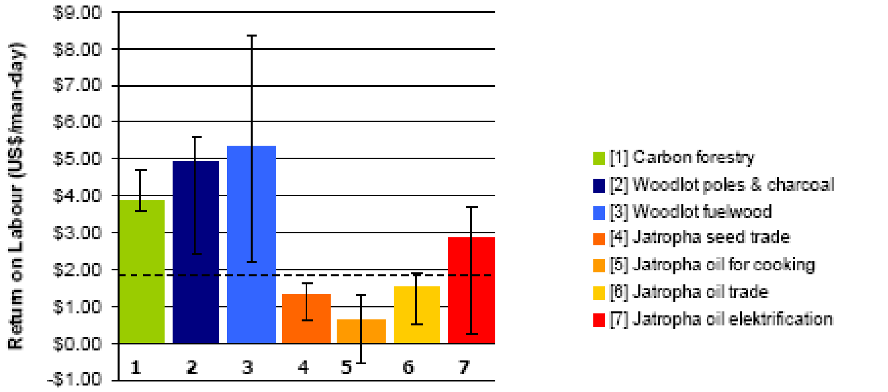
The socio-economic impacts of different bioenergy systems may vary widely, depending on the local conditions. Wiskerke (2008) analysed the costs and benefits of three alternative sustainable biomass energy supply systems for rural households in Shinyanga in Tanzania:

1. Small-scale forestation project for carbon sequestration under the Clean Development Mechanism (CDM) of the Kyoto Protocol or on the voluntary carbon market, which at the same time can be a sustainable source of fuelwood for a local community.
2. A short rotation woodlot for the production of fuelwood or charcoal, optionally with intercropping.
3. A Jatropha curcas L. plantation. The yielded Jatropha oil can be used as a cooking fuel, it can be traded, used as a diesel substitute for off-grid household electrification or it can be used as an ingredient for soap production.

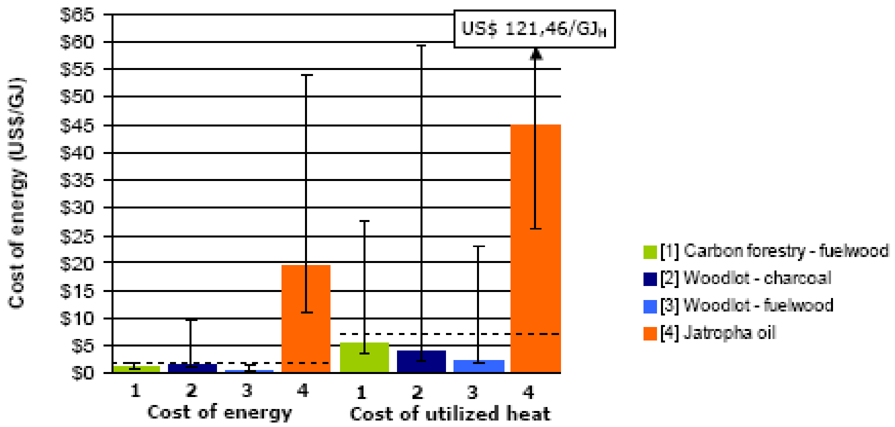
In the following graphs, the Net Present Value (NPV) per hectare, the return on labour and the cost of energy are compared for the various systems. The error bars are based on uncertainty in the main input parameters, namely the shadow cost of labour, the discount rate, the fuelwood market price, the mean annual growth increment, the cost costs of energy market price, the charcoal kiln efficiency, the Jatropha seed yield and the Jatropha plantation size.



S1: System comparison of the NPV per hectare, including error bars. Woodlots are with intercropping. The baseline NPV of maize cultivation is defined as zero, compared to these systems.



S2: System comparison of the Return on labour. The dashed line indicates the baseline Return on labour of a maize-fallow system.



S3: System comparison of the Cost of energy and the Cost of utilized heat for household cooking, when applying best practise cooking efficiency. The dashed lines indicate the baseline average cost of fuelwood of Tsh 600 per headload.

The results show that local fuelwood supply by means of a carbon forestry project is not economically feasible in semi-arid Shinyanga. The yields are too low and the risk of fire is high. However, this analysis does not include the forest benefits experienced by a local community and the indirect benefits of combating land degradation. Such forest benefits for a local community can be significant, as indicated by Monela et al. (2005). Based on these benefits, donor organizations might be willing to finance the gap in the NPV of carbon forestry.

Rotational woodlots are highly economical in semi-arid Shinyanga, when government fees are excluded. The NPV is maximized when producing poles from stem wood and charcoal from branches, while practicing intercropping of maize. However, the return on labour is maximized when producing poles and fuelwood on a monoculture woodlot, since this has the lowest labour intensity. Thus, a farmer who is constraint by land and wishes to maximize added value per unit of land is better of by producing poles and charcoal and applying intercropping, while a farmer who is constraint by labour and wishes to maximize his/her return on labour is better of by producing poles and fuelwood from monoculture. However, when the government fees on wood production from woodlots are included, the economic profitability quickly diminishes. When producing fuelwood or charcoal from a 1 hectare woodlot, the total tax burden erases all potential profits.

The woodfuel production cost price is under the baseline cost of charcoal. When applying best practice cooking efficiency and a kiln efficiency of 30%, the heat production per hectare is about equal for fuelwood and charcoal, since charcoal has an higher end-use energy efficiency.

The potential of jatropha seed production is still highly uncertain. Jatropha oil is too expensive for utilization as an alternative cooking fuel. It is better suited as a blend in local diesel engines, since the production cost is half of the market price of diesel in rural Shinyanga. Jatropha oil can be used as an alternative to diesel in rural electrification projects. For the production of biodiesel, Jatropha oil has to be processed by means of transesterification. This is a capital intensive process that is only feasible when Jatropha oil production is further scaled up and a larger market is created. Utilizing Jatropha oil for soap production is very profitable for smallholders, although this is still a niche market.

It can be concluded that from a smallholder perspective rotational woodlots are preferable for maximizing income and producing low-cost household energy. Jatropha oil is only economical as a local diesel substitute or as an ingredient for soap production. From a government perspective, the positive socio-economic and ecological effects of carbon forestry might compensate for the financial gap between costs and benefits, caused by the low growth increment in semi-arid Shinyanga.

Source: adjusted from W. Wiskerke, 2008.

7 Outlook: Combining bioenergy production and use with improved agricultural systems

Traditional biomass energy systems are still widely used in sub-Saharan Africa. The energetic efficiency of these traditional systems is low and, depending on the prices assumed for biomass, the costs for heating and cooking can be quite high. Other disadvantages of traditional biomass systems are indoor air pollution, the risk of fire and other accidents, and the environmental impacts of fuelwood collection. The World Health Organisation (WHO) estimates that a quarter of the 1.6 million people who die from lengthy exposure to excessive levels of smoke in their homes from cooking fires occur in Africa, and are mostly women and children from the poorest sections of the population (ITDG, 2005). Further, the labour and time intensive collection of fuelwood poses a large burden on the women that manage these systems.

Already small improvements in stoves, charcoal production and switching fuels can increase the efficiency by several tens of percent points, reduce the costs and also avoid or reduce the other negative effects associated with traditional biomass energy systems. However, switching fuels can also increase costs (e.g. switching) to kerosene and improved equipment can lead to high investment costs. The potential for improved traditional biomass energy systems is enormous, as projections indicate that traditional biomass energy systems will be the main energy system for households in sub-Saharan Africa. Crucial for the success of improved traditional biomass systems are the local conditions and economics of these systems.

Further, there is growing belief and confidence that modern bioenergy systems can contribute to reaching development goals and improve profits. Potentially promising biomass systems are:

- Pure plant oil. Pure plant oil from e.g. jatropha and palm trees can be used directly in diesel engines to drive grain mills or water pumps. Pure plant oil can also be used for the production of biodiesel for rural electrification, using diesel engines or for road transportation. Also the export pure plant oil or biodiesel is a potentially promising option, although the export market is largely policy driven and thus uncertain.
- Ethanol. Ethanol can be made from cassava, sugar cane or sweet sorghum. Various biofuels programmes are currently being implemented in several countries in sub-Saharan Africa (Malawi, Ethiopia, Uganda, Tanzania, Sudan, South Africa, Kenya), which focus on first-generation biofuels, both for local use and for export. However, the export of these fuels is hampered by various economic barriers (high production costs, high import tariffs in industrialized countries) and the export market is largely policy driven and thus uncertain.

- Second generation biofuels (ethanol, Fischer Tropsch Diesel). On the longer term, second generation biofuels, which are made from lignocellulosic biomass, are expected to become economically competitive with conventional gasoline and diesel, assuming that several technological hurdles will be overtaken. Sub-Saharan Africa has the potential to become an important, low-cost, large-scale producer and exporter of second generation biofuels. But also the production and export of untreated lignocellulosic biomass to industrialized countries is a potentially interesting option, because second generation biofuels plants will most likely be build in industrialized countries.
- The production of biogas. This is a particularly interesting option for households in rural areas, where organic wastes are readily available at low costs, because of the saving in firewood (and thereby workload), saving in crop waste and saving in fossil fuels.
- The production of electricity and heat from lignocellulosic biomass. The demand for electricity and heat is increasing rapidly in sub-Saharan Africa. Various small and medium scale technologies are available that are potentially interesting, particularly in regions where residues are available at low costs, such as the use of bagasse for cogeneration in sugar mills.

It can be concluded that improved biomass energy can play critical role across the whole spectrum of development activities and are a powerful engine for social and economic growth.

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