Biofuels – An overview

Final Report
May 2007

Prepared for: DGIS/DMW/IB
By: Júlio F.M. de Castro

Acknowledgements

I would like very much to thank Mr. Boris E. Utria, Senior Economist, Energy Unit - Africa Region, The World Bank and Mr. Piet Visser Senior Biomass Specialist from the Biogas Technology Group who have peer reviewed this study. Their comments and suggestions have led to significant improvements of the original text. The responsibility for the study remains evidently with the author.

Table of Contents

Acronyms and Abbreviations

CO	Carbon monoxide
CO2	Carbon dioxide
FCFA	Franc of the French Speaking Countries of Africa.
GHG	Greenhouse Gasses
LPG	Liquefied Petroleum Gasses
MJ	Megajoule
MW	Megawatt
MTBE	Methyl tert-butyl ether
Mtoe	Metric tons of oil equivalent
NOx	Nitrogen oxides
SADC	Southern African Development Community
PPO	Pure plant oil
USA	United States of America
US$	USA Dollar
WB	World Bank

Chapter I – Introduction

Liquid biofuels made from biomass are attracting increasing interest worldwide. Industrial countries see biofuels as a way of reducing Greenhouse Gas (GHG) emissions from the transport sector, while developing countries see biofuels as a way to stimulate rural development, create jobs, and save foreign exchange. Recent surges in the world oil price have prompted a wide range of countries to consider biofuels programmes. Modern biofuels (and bioenergy in general) have the potential to reduce the carbon intensity of development and could come to play an interesting role in supplementing the energy supply mix in both developed and developing countries.

In many countries, developing as well as industrialised, bioenergy (of which biofuels are a subset) has become a centrepiece of renewable energy plans and policies because of its many practical, social and economic advantages. More fundamentally, modern bioenergy is now widely regarded as an important player in the global transition to a low-carbon energy future which is needed to reduce human-induced climate change. This enthusiasm is based on five key advantages that modern bioenergy offers compared to fossil fuels and/or other renewable energy sources:

- *Widely available resource:* Biomass resources are diverse and widespread, often in large volumes. Bioenergy can be produced, in principle, wherever trees and food are grown and wherever food and fibre are processed. This is in marked contrast to the geographic concentration of the oil and gas resources that drive today's industrial activity.
- *Available on demand:* Biomass is a form of stored energy and can therefore provide energy at all times, without the need for expensive storage devices such as batteries. In this respect bioenergy is like fossil fuels and differs markedly from intermittent renewable energy sources such as solar, wind, wave and hydropower, with their nightly, seasonal or sporadic supply shut-downs. Bioenergy is also presently much cheaper – and further advanced – than likely alternatives for non-intermittent renewable energy supplies, such as stored hydrogen derived from wind or solar photovoltaics (PV) via the electrolysis of water.
- *Convertible to convenient forms:* Biomass can provide all the major energy carriers – electricity, gases, liquid fuels for transport and stationary uses, and heat, and it is well-suited to doing this on a decentralised (stand-alone) basis. Biomass can therefore substitute for fossil fuels or other energy supplies in many contexts; and is well-suited to supply the fuels and power at small scales that are needed to underpin poverty reduction, development and growth for the two billion or so people who now lack access to modern forms of energy. Modern bioenergy technologies can also serve similar ends by replacing traditional cooking fuels with clean, smokeless, efficient and easily-controlled liquid and gas alternatives based on renewable biomass rather than fossil fuels.
- *Potential to contribute to greenhouse gas reductions and other environmental objectives:* Bioenergy can be climate friendly. In contrast to fossil fuels, its production and

use emits little or no carbon dioxide, a potent greenhouse gas, provided that the biomass is sustainably generated. In this case, the carbon dioxide that is released when biomass fuels are burned will be re-absorbed from the atmosphere during biomass re-growth. It is important, however, to also consider the net life-cycle

- *Source of rural livelihoods:* Much of the value added and income-generation from bioenergy systems is retained locally and can help to reduce rural poverty – in sharp contrast to fossil fuel or central electricity production and distribution systems, and to many other renewable energy technologies. Indeed, modern bioenergy is widely thought to be a key means of promoting rural development. In many developed countries, biomass fuel production has been promoted as a way of supporting and diversifying unstable farm incomes. In developing countries, modern bioenergy can provide a basis for rural employment and income generation, thus helping to vitalize rural economies and curb urban migration. For many forestry and agro-processing industries biomass provides an abundant, dependable and cheap fuel which can reduce energy costs and earn substantial revenues from the sale of surplus power to the electricity grid or biofuels to urban demand centres or export markets.

In this study only liquid biofuels will be analysed, of which the main division is between alcohols and oils. Of the alcohols this study will only deal with the most common used, namely ethanol. The table below gives an overview of the presently most used conversion processes for biomass [1].

Table 1 - Overview of biomass biochemical and chemical conversion processes.

Fuel	Substitute for	Process	Fuel/Yield MJ/ton Substrate (dry)	Process Energy Requirements MJ/ton	World Mkt. Cost US$ bbl of oil equivalent
Methane	LPG	Anaerobic Digestion	0.28-0.74	1.2	28
Ethanol (C_2H_5OH)	Gasoline	Hydrolysis and/or carbohydrate fermentation	0.46	1.1 – 1.4	68
Methyl and Ethyl esters of vegetable oils	Diesel fuel	Extraction and trans-esterification of vegetable oils	0.30 (a)	0.2	97

Note: (a) Calculated as castor oil.

Objectives of the study

The overall objective of this desk study is to get an overview of the most relevant liquid biofuels especially in the African context, and more specifically in the Netherlands' relevant partner countries.

The study will focus on biofuels for transport, but will also consider biofuels for cooking and power generation. Biogas the result of anaerobic fermentation which can be used for cooking, lighting and electricity generation will not be considered in this study…

Liquid biofuels are usually divided into alcohols that are used to substitute for gasoline and oils that are used to substitute for diesel and are often called Biodiesel, and this division will be followed in this study.

In chapter II we will analyse several aspects of the use of alcohols particularly ethanol, in chapter III the same analysis will be done for oils, using as example the very promising Jatropha oil. In chapter IV we will analyse socio-economic issues of the use of these biofuels. There is no concluding chapter as it was not the intention of this study to draw conclusions but only to give an overview of these fuels and related issues.

Chapter II – Ethanol

2.1 Outlook

Ethanol can be used in gasoline vehicles with minor adaptations. Actually Nikolaus Otto designed the first internal combustion motor to run on ethanol. Ethanol is an alcohol-based alternative fuel produced by fermenting and distilling biomass with an high sugar content such as sugarcane, sugar beets, molasses (a residual product of sugar production). Another way is to ferment and distillate sugar starch crops that have first been converted into simple sugars (saccharification). Feedstocks for this include corn, barley, sorghum, potatoes, cassava and wheat. Ethanol can also be produced from "cellulosic biomass" such as trees and grasses.

Methanol, also known as wood alcohol, can be used as an alternative fuel in flexible fuel vehicles. Methanol is at present predominantly produced by steam reforming of natural gas to create a synthesis gas, which is then fed into a reactor vessel in the presence of a catalyst to produce methanol and water vapour. We will not consider methanol in this analysis because it is not produced from biomass, and because of its high toxicity has not been a fuel of choice for transportation or any other energy use.

Ethanol (ethyl alcohol, grain alcohol) is a clear, colourless liquid with a characteristic, agreeable odour. In dilute aqueous solution, it has a somewhat sweet flavour, but in more concentrated solutions it has a burning taste. Ethanol, C_2H_5OH, is an alcohol, a group of chemical compounds whose molecules contain a hydroxyl group, -OH, bounded to a carbon atom.

Ethanol has a density of 0.789 g/ml at 20°C, boils at 78.5°C, and melts at -114.1°C. Its low freezing point has made it useful as the fluid in thermometers for temperatures below -40°C, the freezing point of mercury, and for other low-temperature purposes, such as for antifreeze in automobile radiators.

Ethanol, which is the same chemical as the alcohol in alcoholic beverages, can reach 96% purity by volume by distillation, and is as clear as water. Ethanol in water cannot be purified beyond 96% by distillation. This concentration (called azeotropic) is enough for straight-ethanol combustion. For blending with gasoline, purities of 99.5 to 99.9% are required, depending on temperature, to avoid separation. These purities are produced using additional industrial processes.

The use of ethanol as a fuel in transportation was formerly mainly to increase the octane level and improve the emissions quality of gasoline, but today is increasingly being used as a partial or total replacement for gasoline in cars and other road vehicles. Ethanol (either straight or jellified) can also be used in households for cooking as a substitute of wood, charcoal or kerosene and for lighting as a substitute of kerosene. Beyond its possible use as fuel, ethanol can be produced for use in beverages and in a variety of industrial applications including cosmetics and pharmaceuticals. As a solvent for the pharmaceutical industry, ethanol is useful for processing antibiotics, vaccines, tablets, pills, and vitamins. Ethanol is used as a solvent in the manufacture of many other substances including paints, lacquer, and explosives. Industrial ethanol is used as a raw material for the production of vinegar and yeast, and similarly in chemical processing as a chemical intermediate. Even food products like extracts, flavourings, and glazes contain large amounts of alcohol. The ethanol is also used in some liquid animal feed products as an energy source.

Cellulosic ethanol

There is also growing interest in the use of waste biomass as feedstock for alcohol production. New technologies to convert cellulose to ethanol, such as Cellulosic Hydrolisis, could provide much higher positive energy ratios of 2 to 3 times more energy in the ethanol produced than energy input. Cellulose to ethanol production could also run on any cellulose and hemicellulose source from farm waste, hay/grass, basically any plant matter including wood, cardboard and paper. Cellulose to ethanol production is still in development and has seen limited use in industrial ethanol production. However, a bioenergy corporation in Canada is producing 1 million gallons/year of cellulosic ethanol from their Ottawa facility. Using current technologies, 1 ton of biomass (such as switchgrass) would be able to produce 80 gallons of ethanol using a conventional enzymatic fermentation process. [2]

Gelfuel

Gelfuel is currently being distributed in several countries in Africa as a fuel for cooking. To produce gelfuel, ethanol is mixed with a thickening agent (for example cellulose) and water through a very simple technical process, resulting in a combustible gel. Gelfuel has several advantages compared to straight ethanol: one can not drink it, it is easier and less dangerous to store, sell and transport, and it is less likely to have fire in the household because if the stove falls the burning gel does not spread. The main disadvantage is that it is up to 25% more expensive than straight ethanol, and this makes it less competitive. Also now-a-days straight cheap ethanol burners have been developed that are very efficient and safer.

2.2 Ethanol as automotive fuel

Ethanol is used as an automotive fuel by itself and can be mixed with gasoline to form what is called "gasohol". Because the ethanol molecule contains oxygen, it allows the engine to more completely combust the fuel, resulting in the emission of cleaner exhaust gasses. Since ethanol is produced from plants that harness the power of the sun, ethanol is also considered a renewable fuel. Therefore, ethanol has many advantages as an automotive fuel.

There has long been widespread acknowledgement that ethanol is a cleaner-burning fuel than gasoline. Ethanol has far fewer standard regulated pollutants such as carbon monoxide and hydrocarbons, compared with plain gasoline in equivalent tests. There has been concern about increased evaporative smog-forming hydrocarbon emissions. For example, some claim that adding ethanol to gasoline will at best have no effect on air quality and could even make it worse. Studies show ethanol could even increase emissions of nitrogen oxides and volatile organic compounds, which are major ingredients of smog. Other critics have argued that the beneficial effects of ethanol can be achieved with other cheaper additives made from petroleum.

It is important to distinguish the issues. Ethanol in a blend with gasoline replaces tetra ethyl lead, benzene and methyl tert-butyl ether (MTBE) -- all of which are additives that are meant to raise octane levels. Ethanol, with an octane rating of 113, far surpasses regular gasoline and precludes needs for other dangerous additives. However, ethanol can increase vapour pressure of gasoline causing increased evaporative emissions which, on balance, are far less serious than lead, benzene or MTBE. For example, there is evidence of serious water table contamination caused by MTBE, and it has now been legally banned in the USA. Yet, there are indications that oil companies are still actively promoting the use of "cleaner gasoline" containing MTBE in developing countries.

Engine modifications

Pure ethanol reacts with or dissolves certain rubber and plastic materials and cannot be used in unmodified engines. Additionally, pure ethanol has a much higher octane rating (113) than ordinary gasoline, requiring changes to the compression ratio or spark timing to obtain maximum benefit. To change a gasoline-fuelled car into a pure-ethanol-fuelled car, larger carburettor jets (about 30-40% larger by area) are needed. A cold starting system is also needed to ensure sufficient vaporisation for temperatures below 15 °C (59 °F) to maximize combustion and minimize un-combusted non-vaporized ethanol. If 10 to 20% ethanol is mixed with gasoline, no engine modification is typically needed. Many modern cars can run on the mixture very reliably.

Since 2000 an increasing number of vehicles in the world are manufactured with engines which can run on any gasoline from 0% ethanol up to 85% ethanol without modification. Many cars are designed to be dual fuel or flexible fuel vehicles, since they can automatically detect the type of fuel and change the engine's behaviour, principally air-to-fuel ratio and ignition timing to compensate for the different octane levels of the fuel in the engine cylinders.

2.3 Energy balances and environmental effects

There are heavy discussions around the issue of whether biofuels have a positive energy balance, .i.e. that they deliver more energy than the energy which is put into their production. To do this analyses it is required that a detailed energy and input stock analyses be performed, that is, one should consider the aggregate energy input in producing pesticides and fertilizers necessary for crops production, as well as the fuel required to operate farm machinery and to ferment and distil the feed stock. This is a controversial subject charged with potential bias. Much of it depends on what is included and what is excluded from the calculation, particularly when compared with the energy balance of the production of gasoline itself. Analyses are greatly complicated by various methods of accounting for the energy value by-products and consideration of alternate uses of the feedstock. Not surprisingly, this debate has been at best inconclusive to date, and many of the participants in this discussion are biased, because they have direct interests, either with the oil industry or with the agricultural system.

In this regard, geography is the decisive factor. In tropical regions with abundant water and land resources, such as Brazil the viability of production of ethanol from sugarcane is no longer in question; in fact, the burning of sugarcane residues (bagasse) generates far more energy than needed to operate the ethanol plants, and many of them are now selling electric energy to the utilities. The discussion is particularly heavy around the net benefits of the production of ethanol from corn in the USA, where the results vary from overly negative to modest positive energy balances. Also, many argue that the ethanol production programmes in the USA are another avenue to subsidise mid-west farmers that otherwise would have gone out of business because of lack of competitiveness for their corn without large protectionary subsidies. The amount of subsidies to the farming system and ethanol industry is so high that the same policy objectives (energy security, environmental benefits, etc.) could be attained with much lower inputs [3]. One USA government study [4], examined subsidies historically given to the oil industry and to the ethanol industry and found that the amounts of those to the oil industry are far higher. That analysis did not take into account the costs of "securing" these supplies from countries potentially unwilling to cooperate. Therefore this represents as said above a conflict of interests.

According to [39] the production of one MJ of ethanol from corn requires the input of 0.74 MJ of fossil fuels, thus the energy balance is 1.35. In order to eliminate the use of non-alcohol fuels, it would be necessary to produce two units of alcohol for each unit of alcohol delivered to the consumer that means a minimum energy balance of 2 is required. It should be noted that the production of gasoline has a negative energy balance, for every MJ of gasoline delivered it requires 1.23 MJ of fossil fuels [39], but this is the price to pay to have a highly convenient fuel. The same study indicates that only 0.12 MJ of fossil fuels are needed to produce one unit of ethanol from sugarcane, an energy balance of 8.3.

Local environmental effects

The introduction of ethanol as fuel for transport has considerable local environmental benefits. The most basic is when ethanol is used as octane enhancer and substitutes lead in gasoline. The large experience in Brazil with the introduction of ethanol shows that the local air quality has improved greatly as measured by the total removal of lead from gasoline, the sharp decrease in CO, unburned hydrocarbons and NO_x emissions. The increased emissions of acetaldehyde are much less preoccupying than the formaldehyde emitted by gasoline-fuelled engines. However, regulatory pressure in recent years, led to considerable improvement in the emissions of gasoline-fuelled engines, to the point that today they are, except for aldehydes, very similar.

Concerning its use as cooking fuel, the local environmental effects of the utilisation of ethanol or gelfuel (a mixture of ethanol and a thickening agent) occur by the substitution of charcoal or fuelwood by a fuel which is based in a renewable stock and can be produced sustainably and without any known large impact on the environment (when the agricultural chain is governed by simple principles in the management of water, fertilizer and pesticide use, and the agro-industrial production is set-up respecting basic environmental and quality principles). The global effects of its use are accrued by the substitution of unsustainably produced charcoal and fuelwood, or the replacement of fossil fuels such as kerosene and LPG.

Global environmental effects

The most acclaimed global effect of the introduction of ethanol is the reduction of the emissions of greenhouse gasses. However, the value of the benefits of ethanol in this respect is subject to the same intense discussion as with the energy benefits (the two things are intrinsically linked), and the results depends on as much factors as one can consider, but at least for ethanol produced from sugarcane stands without doubt that the balance is (very) positive. It should be noted that the overwhelming majority of non-USA ethanol programmes is not based on corn, and one should be careful in producing ethanol from corn in developing countries due to social and food security reasons.

If we take for example Brazilian data, the production and use of sugar and ethanol can avoid the emission of 207 kg CO_2 per ton of sugarcane, as detailed in table 2. The utilization of ethanol and sugarcane bagasse as fuels avoids the emission of 12.7 million tons of CO_2 annually, and thus reduces Brazilian emissions of CO_2 from fossil fuels by 20 percent (quotation from [1], original source given below).

Table 2 - GHG in the Production of Sugarcane, Sugar and Alcohol, 1998.

Basis: kg of GHG expressed as kg CO_2 per metric tonne of sugarcane		
	Production, harvest and transport of sugarcane	
1.1	Carbon sequestration via photosynthesis	**+ 694.7**
1.2	CO_2 from diesel used in sugarcane agriculture	**- 4.7**
1.3	CO_2 from burning dry leaves, tips	**- 198.0**
1.4	Other GHG, especially CH_4, from burning dry leaves, tips	**- 1.0 ~ - 5.0**
1.5	N_2O from soil from nitrogen fertilization	**- 3.2**
1.6	CO_2 from fossil fuels used in agricultural inputs (seedlings, etc.)	**- 6.7**
1.7	CO_2 from fossil fuels used in manufacturing agricultural implements	**- 2.4**
1.8	Oxidation of sugarcane residues left in the field	**- 49.5**
	Production of sugar and alcohol (45% to sugar, 55% to alcohol)	
2.1	CO_2 from fermentation	**- 38.1**
2.2	CO_2 from fossil fuels in manufacturing inputs (lime, sulphuric acid, etc.)	**- 0.5**
2.3	CO_2 from fossil fuels in manufacturing equipment, installations and bldgs.	**- 2.8**
2.4	CO_2 from burning all the bagasse, replacing fuel oil, for sugar and alcohol	**- 231.6**
2.5	Avoided carbon emission in sugar making by the use of bagasse	**+104.0**
	Utilization of final products: sugar and alcohol	
3.1	Metabolic sugar carbon return to atmosphere	**- 97.0**
3.2	CO_2 from alcohol burned in automotive engines	**- 79.1**
3.3	Avoided carbon emission from automotive engines by the use of alcohol	**+126.7**
TOTAL AVOIDED EMISSIONS		**+206.8**

Source: Macedo, Isaias de Carvalho, *"O Ciclo da Cana-de-Açúcar e Reduções Adicionais nas Emissões de CO_2" (The Sugarcane Cycle and Additional Reductions in CO_2 Emissions),* Centro de Tecnologia Copersucar, Piracicaba, Brazil, mimeo

2.4 The Brazilian experience

A number of countries have developed significant bio-ethanol programs: Brazil (from sugarcane), the United States (from corn), and France (from sugar beet). The ethanol program in the USA is more driven by the subsidy policy to support farmers and now for "energy and national security reasons", than by the net energy balance of producing ethanol from corn. The top five fuel ethanol producers (in million litres) in 2005 are: Brazil (16,500), USA (16,230), China (2,000), European Union (950) and India (300) [35]. The largest experience is that from Brazil and for that reason will be looked in the detail.

Ethanol fuels in Brazil

All data in this chapter below is taken from reference [1]. The largest alternative transport fuels program in the world was Brazil's ProAlcool Programme. About 8.4 million metric tons of oil equivalent (Mtoe) of ethanol have been consumed in 1998 (equivalent to some 167,000 barrels of crude oil per day or 217 thousand barrels of gasoline per day) and corresponds to about 20% of fuels consumed in transportation in the country. About 60 percent is neat or hydrous ethanol and 40 percent is anhydrous ethanol for blending with gasoline. The total primary energy supplied to the Brazilian economy in 1998 was 250 million Mtoe, and some 4 million vehicles, about a quarter of the total vehicle fleet, ran on hydrous or "neat" ethanol. The main transportation fuel in the country is diesel oil consumed at a rate twice that of gasoline. Gasoline in Brazil is actually defined by three grades: gasoline A (regular, leaded gasoline), which has been fully replaced by gasoline C, a blend of gasoline and up to 25% anhydrous ethanol by volume; and gasoline B (premium gasoline), which has been discontinued as a result of neat ethanol market penetration.

The Brazilian sugar cane economy

In 1997 Brazil produced 25% of the world output of sugarcane, some 300 million tons annually. There are 70 thousand sugarcane producers in the country and 90 percent in areas smaller than 150 hectares. The total area under sugarcane in the country by the end of 2005 reached 6 million hectares – equivalent to 0.6% of the total arable land in the country [40] – and about 70% of that sugarcane area is located in the state of São Paulo. Some 343 sugar mills and ethanol distilleries are presently in operation, 202 producing sugar and ethanol, 122 producing exclusively ethanol and 19 making sugar only. Overall the industry contributes one percent of the GDP of Brazil. Sugarcane bagasse is used as fuel in raising industrial steam and generating electricity for the mills, distilleries and the electrical grid. Together with ethanol, sugarcane bagasse contributes 13% of the domestic production of energy in the country. The potential of surplus electricity from sugarcane bagasse and other residues in co-generation systems is estimated at 5 thousand MW or about 10% of the present power generation capacity in the country. The value of avoided gasoline imports at 200 thousand barrels a day reaches over US$ 2 billion per year. The sugarcane economy in Brazil generates one million direct jobs, of which 75% in sugarcane agriculture and 25% in the production of ethanol.

2.5 The African experience

The situation concerning ethanol in Africa shows that some countries are in advanced stage of planning the introduction, others are already producing ethanol, and other have already set mandatory mixing of ethanol into gasoline. Below is a review of information found in the literature and on internet and from own observations and reports.

Also recently (July 2006) thirteen of Africa's poorest nations have joined forces to become global suppliers of biofuels. In a meeting in Senegal, they formed the African Non-Petroleum Producers Association, aimed at developing alternative energy sources [5].

2.5.1 Ethiopia

Ethanol is currently being produced in Ethiopia at the FINCHAA sugar mill which produces 8 million litres a year at a state-of-the art ethanol distillery. The original idea was to mix it with imported gasoline, but this idea met considerable resistance from the petroleum industry, and the ethanol was directed to be mixed with kerosene for the household market (i.e., "K-50" in a mix of 50% kerosene and 50% ethanol). This effort however met with strong market resistance as the kerosene-ethanol mixture proved to be too volatile and resulted in several house fires. This set-back was the result of insufficient research and adaptation of the stoves to be used and the very hazards of the fuel mix. In 2006 the WB was developing a project idea to produce ethanol at METHARA sugar mill (besides cogeneration of electricity and heat) to utilise waste bagasse and surplus molasses. The ethanol fermentation facility would produce 10 million litres a year and it was intended to be sold to households as a substitute for woodfuels and imported kerosene [6]. Also in 2005, 850 ethanol fuelled stoves were tested in Addis Ababa as part of a pilot test programme [7].

A study [8], undertaken with World Bank support, to assess the potential to produce and market denatured ethanol and gelfuel as cooking fuels in Ethiopia (2002 and up-dated in 2004) concluded that: **(i)** both straight ethanol and gelfuel would be competitive fuels in the Ethiopian household energy market; **(ii)** a potential urban household market in excess of 50 million litres/year exists for both fuels; **(iii)** current ethanol production capacity at FINCHAA would cover less than 20% of the estimated potential demand by the household sector; **(iv)** current ethanol production capacity of 8 million litres/year (FINCHAA), could be boosted to 12 million litres/year with minimal investments; **(v)** with further investment in ethanol distillation capacity at the Methara and Wonji-Shoa sugar factories, ethanol production could be further increased to 34 million litres/year by using the 23,000 tonnes of available molasses; **(v)** there is an additional 388,000 hectares that could be put under immediate sugarcane development, which in addition to sugar and electricity could provide more than 2 billion litres/year of ethanol; and; **(vi)** there yet exist an area of approximately 10 million hectares suitable for both for perennial and annual crops in areas below 1500 m spread over seven Regional States, of which some fraction could be eventually devoted to the production of ethanol (sugarcane, sweet sorghum, cassava, cashew apples, etc.) and bio-diesel (Jatropha, soy, rape seed, etc.) bearing crops, without creating competition for land between food and energy production. If, for instance, 20 percent of that area was devoted to a combination of sugarcane and sweet sorghum it would be possible to produce more than 10 billion litres/year of ethanol.

2.5.2 Senegal

According to a Senegalese newspaper [9] the "Compagnie Sucrière Sénégalaise will invest US$ 6 million to produce 21,5 million litres ethanol per year from surplus sugar molasses. The production facility will be open in 2007 and the feasibility studies were done with Dutch support.

2.5.3 Benin

A study [10] commissioned by the UEMOA presented at a workshop in Dakar in November 2006, indicates that the most suitable raw material for the production of ethanol /gelfuel in Benin is cassava. With an average production of 2.8 million tonnes of cassava per annum, Benin could produce 20,000 m3 of ethanol by using just 5% of harvests (no competition with food supply needs).

2.5.4 Burkina Faso

The same study [10] suggests that sugar cane seems to be the most accessible raw material for the production of ethanol at present, based on new cultivations. If the 5,000 ha owned by SOSUCO were used for this purpose, one can reasonably estimate the production of ethanol at 20,000 m3 per annum. The energy required for the conversion of sugar cane juice to ethanol could be provided by bagasse. Another potential source is the sugar sorghum if the plantation envisaged in the Sourou Valley becomes a reality.

2.5.5 Ivory Coast

The country has a large potential to produce ethanol as a result of extensive availability of cheap molasses, enabling the profitable production of ethanol and gelfuel. The potential is 19,000 m3/yr. Production costs are estimated at 121 and 165 FCFA/l for ethanol and gelfuel respectively [10].

2.5.6 Guinea- Bissau

The cashew tree apple currently seems to be the most suitable raw material to use for the production of ethanol. The annual production is estimated at 400-600 thousand tonnes, of which only 30% are employed for the production of juice, wine and spirits. If the remaining 70% could be used to produce ethanol, the ethanol production potential would be approximately 8,400-12,600 m3/yr [10].

2.5.7 Mali

The real production potential depends mainly on the new sugar mill in Markala. The envisaged output of 170,000 tonnes of sugar per annum will result in an availability of 61,000 tonnes of molasses per annum, which can be converted into 18,000 m3 of ethanol [10].

2.5.8 Nigeria

There are plans for a 10 to 20,000 hectare sugarcane plantation fitted with an ethanol production unit capable of producing 70 to 80 million litres annually, and an 5 to 10,000 cassava plantation fitted with an ethanol production unit capable of producing 50 to 60 million litres annually. Ethanol will be commercialised as a motor fuel for blends up to 10%. [40].

2.5.9 Togo

In spite of the presence of a small sugar industry, the immediate potential for the production of ethanol is low unless new sugar cane plantations are developed to replace industrial pineapple plantations [10].

2.5.10 SADC region

A study [11] indicates that there is a high potential for producing biofuels in the Southern African Development Community (SADC) region. As an indication that study showed the potential arable land still available in five selected countries, and the amounts of land required for own consumption:

Table 3 - Arable land potential (million of ha) for five selected SADC countries.

Country	Land Area	Suitable Cropland (~ 20 %)	Area Under Crops Today	Area Required For Domestic Energy Supply
DRC	227	45	8	0.2
Angola	125	25	4	0.6
Tanzania	88	18	5	0.3
Zambia	74	15	5	0.2
Mozambique	78	16	3	0.2

2.5.11 Malawi

In order to improve the security and reliability of energy supply systems the government of Malawi is working with the private sector to encourage the expansion of fuel-ethanol production capacity to maintain a 20:80 petrol-ethanol blend and support other fuel-ethanol applications such as gelfuel, etc.

Malawi has typically favourable economic conditions for ethanol production, and as a result has been producing and blending ethanol in its gasoline since 1982. Because of its landlocked nature and high freight costs, the wholesale price of imported gasoline is high. For the same reason, Malawi's molasses has a low value because the cost of shipping to port for export typically exceeds the world market price. Thus Malawi's Ethanol Company Ltd (Ethco) in 2004 used molasses as its fermentation feedstock in its Dwangwa distillery to produce about 10 to12 million litres ethanol per year. Full production capacity of the Dwangwa distillery is 60,000 litres per day, so in theory it can produce up to 18 million litres per annum. However production has largely been constrained by molasses feedstock supply. As a result of these ethanol supply constraints instead of the maximum 20:80 blend being achieved, it has averaged about 12:88.

It has been decided that Malawi is to move completely to the use of unleaded gasoline as of January 2005. Apparently, as refined high octane fuel is imported, the blend volume is reduced to 10%, thus reducing the annual requirement of ethanol for blending to about 10 million litres. In other words, the ethanol will now be used as a gasoline extender, rather than as a replacement for lead as an octane booster, hence the lower blending ratio.

Construction on a second distillery was started in 2003 in the south of the country at Nchalo, with the intention of using molasses feedstock from Sucoma's nearby sugar mill. This project is being undertaken by Press Cane, a joint venture between two Malawian companies, the ubiquitous Press Corporation, which is also the major shareholder in Ethco, and Cane Products. Planned production by Press Cane is a further 60,000 litres per day, in other words doubling the country's ethanol supply. All data on Malawi from [13].

Gelfuel is presently being marketed in Malawi. Its acceptability by the population has been good, even though its dissemination has been hampered by the lack of a consistent and persisting promotion campaign. The results of tests done by Biomass Technology Group in The Netherlands in June 2004 (estimated at 75 meals per month and using prevailing fuel costs in Malawi) showed, that gelfuel was not competitive with other fuels except marginally competitive with LPG (it should be noted that these cost comparisons were based on an oil price of US$ 22/barrel). On the other hand, straight ethanol burning in an innovative stove developed by Greenheat, a South African company was even at current prices the cheapest alternative. However, the performance of the straight ethanol burner was not verified independently [14].

2.5.12 Mozambique

The Mozambican oil products storage and distribution company Petromoc has also plans to build several ethanol and production facilities and the financing for a number of these has apparently already been secured. The total production planned at several location amounts to 560 million litres ethanol.

The target to be set by the government of Mozambique is 10% ethanol in gasoline. This means that to achieve that target 10 million litres of ethanol (10% of 100 million litres) should be produced every year. Therefore the total planned production greatly exceeds the domestic needs for ethanol, the rest being intended for export, for what

Mozambique is in a good position having preferential tariff agreements with the European Union [15].

2.5.13 South Africa

Ethanol is produced via two routes in South Africa, synthetically and through fermentation. Sasol the chemical conglomerate, a world leader in coal and gas to liquid technologies is amongst the world's largest producers of synthetic ethanol, producing 400 million litres per annum, while Mossgas, a gas to liquid plant, produces a further 160 million litres per year.

There are two main bio-ethanol plants, both of which use molasses from the cane sugar industry as their feedstock, namely Illovo Sugar's Merebank plant which produces 40 million litres and NCP' s plant which produces 25 million litres. Both of these are in Durban, and their product is sold into various ethanol markets, locally and internationally, ranging from industrial through pharmaceutica1 to potable. A number of other smaller distilleries are also in production, but they produce mainly potable alcohol for the beverages industry.

Bulk prices for industrial ethanol which is suitable for use as household fuel are typically R 2.50 (US$ 0.38) per litre for synthetic hydrous (96%) ethanol and R 3.70 (US$ 0.57) per litre for industrial grade bio-ethanol. South African ethanol prices are driven by real costs of production, and to some extent by the international ethanol market, particularly in the case of Sasol's synthetic ethanol. Molasses is currently the main feedstock for bio-ethanol, and in terms of current pricing policy in the South African sugar industry, the molasses price is determined on the basis of its sugar content. The sugar price used is the domestic sugar price, which is set independently of the international sugar spot price, and is generally higher, in order to protect the South African industry from international fluctuations.

In the past five (before June 2004) or so years in South Africa, various initiatives have been taken to enter the household energy market with ethanol-based fuels, with varying degrees of success. All data from [16]

In South Africa gelfuel seems to being increasing accepted by consumers. However, due to the wide availability of kerosene and at very low prices (maximum price is set by the government and there are no taxes or levies on the fuel), kerosene is by far the most used fuel. Only the use of a straight ethanol burner - as also indicated above - makes straight ethanol cheaper than kerosene. However, the same caveat exists as in Malawi, namely there is no independent verification of the achievements of the burner [15].

2.5.14 Zambia

Zambia's gasoline demand stands at about 190 million litres a year [12]. At the intended 10% substitution of gasoline to meet the octane number 91, domestic ethanol production from molasses would just be sufficient. However, molasses can have other uses and gasoline consumption is due to increase and higher blending percentages are possible, requiring therefore new feedstocks for the production of ethanol.

Zambia has significant areas that are suitable for growing sweet sorghum. In comparison with sugarcane, it is easier to grow and handle, at about one third of typical cultivation costs, and also uses significantly less water.

Zambia Sugar has announced that it has the capacity to produce between 12 million litres and 13 million litres of ethanol at the present level of sugar production. Zambia Sugar currently produces 50,000 metric tons of molasses and intends to increase its capacity to 100,000 metric tons by 2010. This would double its ethanol capacity to at least 22 million litres if the company chose to engage exclusively in ethanol production. Currently almost all the molasses it produces goes into the domestic livestock sector. Spanish and Indian investors are reportedly competing to invest in a US$ 150 million sugar plantation Zambia plans to establish. Zambia Investments Centre said a feasibility study was concluded on the Luena sugar plantation in the north of the country, which will process sugar as well as ethanol. Luena has 100,000 hectares of virgin land of which only 30,000 hectares will be used for growing and processing sugarcane while the rest has been earmarked for growing other export crops. The project will grow sugarcane on a 10,000-hectare farm while 20,000 will be for small-scale farmers on an out-grower scheme to be supported by the project. The plantation will have the capacity to produce 250,000 tons of sugar (all data in this paragraph from [40]].

Chapter III – Oils

3.1 Outlook

Vegetable oils can be used without large problems in diesel engines. Actually Rudolf Diesel designed the machine he built to be fuelled by vegetable oil. Vegetable oil based fuels, can be straight oils without any modification and usually called PPO (pure plant oil) and biodiesel (fatty acid methyl ester) which the vegetable oil is put through a process called esterification.

Plant oils consist mainly of glycerides of fatty acids. Fatty acids are saturated and unsaturated aliphatic monocarbon acids, whose chain length is between 4 and 24 carbon atoms. Amongst plant oils tri-glycerides are the most common. In these all 3 hydroxyl groups of glycerides are replaced by fatty acids.

Oils can be obtained from a variety of sources: soybean, sunflower, rapeseed, palm trees, coconut tress, castor trees and also from Jatropha. Rapeseed which is widely used in Europe is less suitable for the African conditions, and we will give here less attention to feedstocks that have a potential use as food and will concentrate on the use of the Jatropha oil. The top five biodiesel producers (in million litres) in 2005 are: Germany (1,920), France (511), USA (290), Italy (227), and Austria (83) [35].

3.2 Jatropha Curcas L.

Among the great variety of oil plants available in tropics and subtropics the oil of the physic nut tree (Jatropha curcas L.) seems to be most suitable for energy applications. The Jatropha plant is a small tree or large shrub which can reach a height of up to 5 m. The life-span of the Jatropha plant is more than 50 years.

Most varieties of this plant produce oils, which are toxic to humans and animals so that they are unsuitable for either food or feed. Jatropha plants are frequently used as hedges to protect plantings in gardens and fields from grazing animals. The plant is adapted to extreme growing conditions and is resistant to drought and therefore allows re-cultivation of desert areas.

Jatropha oil consists of fatty acids, and according to the variety, up to 6.7 % of the oil can be free fatty acids. Sulphur and nitrogen are likewise present in amounts of 0.13 % and 0.11 %, respectively [17].

According to the structural differences between plant oil and fossil fuels, differences in physical and chemical properties between those liquids can be derived. Table 4 shows the different properties of some plant oils in comparison to kerosene and diesel oil.

Table 4 - Physical properties of selected plant oils, kerosene and diesel oil [17].

Oil type	**Ignition Point (°C)**	**Gross Calorific Value (MJ/kg)**
Jatropha	340	39.65
Palm	314	39.54
Rapeseed	317	40.56
Sunflower	316	39.81
Kerosene	50 - 55	43.50
Diesel	55	45.00

The gross calorific value enables an evaluation of total heating energy generated during the combustion process. Gross calorific values of plant oils are in general about 10 percent lower than the ones of kerosene and diesel oil, respectively. According to the similarity of gross calorific values plant oils may be considered as substitute for diesel oil or kerosene as fuel.

Depending on growing conditions seed production per plant varies between 1.5 and 2.0 kg. Seed production is attributed to precipitation and ranges from 0.4 tons per hectare to over 12 t/ha/a. The productivity of Jatropha hedges in Mali seems to be from 0.8 - 1.0 kg of seed per meter of fence which is equivalent to 2.5 to 3.5 tons per hectare and year. In Nicaragua the annual yield of a Jatropha plantation is put at 5,000 kg per ha, in Paraguay the reported yield is 4,000 kg per ha of 8 year old trees. All data in this paragraph from [18].

3.3 Jatropha as automotive fuel

Table 5 below shows the properties of Jatropha oil which are important from the point of view of its use as automotive fuel as compared to diesel.

Table 5 - Jatropha vs. Diesel oil [19].

Jatropha Oil in Comparison with Diesel Fuel		
Parameter	**Diesel**	**Jatropha Oil**
Energy content (MJ/kg)	42.6 - 45.0	39.6 - 41.8
Spec. weight (15/40 °C)	0.84 - 0.85	0.91 - 0.92
Flash point (°C)	80	110 - 240
Cetane value	47.8	51.0
Sulphur (%)	1.0 - 1.2	0.13

After pressing the seeds, the filtered oil can be directly used as PPO in diesel engines. Because of slightly different properties of PPO compared with fossil diesel, newer types of diesel engines must be adapted. Many types of diesel engines have indirect injection (IDI) with pre-chambers. The PPO can be used freely in these engines, which are still commonplace in developing countries. Some typical brand names are: Lister, Deutz, IFA, DMS, and Farymann. Probably most of these are IDI types. Elsbett diesel engines have been designed especially for the use of PPO.

Direct Injection diesels can also run on PPO, but some modifications have to be made to the engines. Mainly cold start and low-load situations (idling etc.) are to be avoided when using PPO. A two-tank system, using PPO only for full load of the hot engine, overcomes most problems. The engine should be monitored properly for lubrication oil production or consumption and coke deposit in the combustion chamber.

Conversion of the engine is meant to overcome three major differences between PPO and diesel:

1. PPO is more viscous (thicker) than diesel at moderate temperatures.
2. Under similar conditions PPO burns slower (has a larger ignition delay) than diesel.
3. It is more difficult with PPO than with diesel to get a complete combustion.

The first problem is mainly an issue in temperate climates or with very viscous oil, like palm oil or castor oil. It mainly affects the flow resistance in the fuel system until the injection pump. The majority of diesel fuel systems are suction systems, driven by the injection pump. If the pump cannot overcome the resistance, the engine won't get enough fuel and will refuse to accelerate. The flow resistance can be overcome by heating the PPO to make it less viscous. Heating with hot coolant is the best option, because coolant is water (or water based) and hence it can deliver a lot of heat, and second because the coolant water has the ideal temperature of close to 100 °C. Other options that should be considered to reduce the flow resistance are placing the tank in a warm location (in case of a stationary engine) and increasing the fuel line diameter. In European PPO conversions the supply line diameter is changed from 6 to 8 mm or more.

To overcome the second and third issue it is important that the injectors are in proper condition. These parts make sure the fuel is atomized (sprayed into very fine droplets) for combustion. In case of pre-chamber car engines in Europe the guideline is kept that the opening pressure of the injector (reflecting its condition) should be checked after 100,000 km. If no special PPO injectors (like offered by Elsbett) are installed, it is advised to increase the opening pressure of the new injectors by 10-20 bar and to advance the injection timing of the engine a bit. If it should remain possible to drive the engine with pure diesel at high loads after conversion, it is recommended not to advance the timing too much, to avoid hard knocking.

Biodiesel production

Instead of adapting the engine to run on PPO, the oil can also be chemically treated to produce biodiesel for any diesel engine, and the PPO can be converted to biodiesel with a trans-esterification process. The resulting biodiesel can be used in any diesel engine without adaptations (except for pure rubber hoses which are damaged after longer contact with pure biodiesel).

The production of biodiesel is essentially a simple chemical process. The vegetable oil molecules (triglycerides) are cut to pieces and connected to alcohol (methanol or ethanol) molecules to form methyl or ethyl esters. As a side product glycerine is formed. This requires the addition of methanol (or ethanol) and caustic soda, increasing the cost of the final product. This is mostly done in Europe, notably in Germany and France, from rapeseed oil. This process requires the use of electricity, and therefore biodiesel production is typically feasible on a large scale, at centralised production plants. It is not so suitable for small scale applications, although small systems have been designed in India, powered by human pedalling force (cycling).

Disadvantages to the user are its slightly lower energy content, leading to an increase in fuel consumption of about 2-10%, and the fact that it works as a solvent. Biodiesel tends to clean the fuel system, taking the dirt that has been gathered during diesel use, and herewith it may cause blocking of the fuel filter. Furthermore its solvent nature may affect the integrity of the fuel lines and gaskets in the fuel system [20].

3.4 Energy balances and environmental effects

Much less is known about the energy balances of the production of biodiesel as compared to ethanol. For biodiesel these energy balances depend greatly from the source of the oil and as in the case of ethanol on the climate. For cultures that are typically used in moderate climates (rapeseed, sunflower) these energy balances are less favourable. Palm oil having the largest oil yield per hectare has probably the most favourable energy balance.

On the other hand palm oil plantations have been up to now mostly created by imposing severe environmental damages, to rain forests in Malaysia and Indonesia. There are large plans to produce biodiesel from soy but again the energy balances and environmental effects are not that good. In Brazil large areas of forests have been destroyed for the production of soy, and there are concerns that the new plans of the Brazilian government to produce biodiesel will even cause more deforestation in the Amazons.

For Jatropha very little is known because there is less experience and because Jatropha has not been cultivated on large scale up to now. However, knowing that there is little input in fertilizers, pesticides and water the energy balance must be overly positive. Due to the fact that it can grow on marginal lands (but an optimal production is achieved in better quality lands), requires little water, and few pesticides and fertilizer, its negative environmental impacts must be small. In [21] it has been reported that Jatropha requires 10% of the energy contained in the oil as energy input for production and processing.

The GHG balances also depend on many factors like for ethanol. Data available in an ESMAP (Energy Sector Management Assistance Programme, World Bank) report [22] gives the following changes in lifecycle GHG emissions per kilometre travelled by replacing diesel with biodiesel in conventional compression ignition vehicles:

Table 6 – Lifecycle balance of replacing diesel in vehicles (1).

Feedstock	***Location***	***Change***
Rapeseed (2)	Germany	-21%
Rapeseed (2)	Netherlands	-38%
Soybeans (2)	Netherlands	-53%
Soybeans (2)	USA	-78%
Tallow	Australia	-55%
Canola	Australia	-54%
Waste coking oil	Australia	-92%
Soybean	Australia	-65%

(1) Source [22], table quoted from several other sources in that report.
(2) Only CO2 emissions are considered.

As one can see the calculated emissions vary widely related to location and calculation assumptions.

A project in Tanzania [37] claims emissions reduction of 42,847 tCO_2e/year based on the production of 12,000 tonnes of biodiesel from Jatropha to be used to substitute diesel in transportation. That is a reduction of 3.6 tCO_2e per ton of biodiesel or 3.13 tCO_2e per litre of biodiesel. Another project in India claims 3 tons of CO_2 equiv. per ton of biodiesel [38].

3.5 Biodiesel in Africa

In Africa there are widespread but very small experiences in many countries with the production of oils for fuel, but there is very little documented experience available.

3.5.1 Burkina Faso

SN CITEC (Dagris Group) plans to build a factory in the short term with a production capacity of 10,000 tonnes per annum based on cottonseed [10].

3.5.2 Mali

Currently, Mali has about 10,000 km of Jatropha hedges with a growth rate of 2,000 km per year, which represents a potential of 1,700,000 litres of oil per year. The average length of these hedges, in those areas of Mali where they are most prevalent, is between 2 and 15 km per village, with a maximum of up to 40 km per village [36].

Jatropha curcas is generally well-known among the populations of Mali and has long been recognized as a plant of many uses. If carefully planted, Jatropha hedges not only protect gardens from hungry livestock but also reduce damage and erosion from wind and water. Traditionally the seeds were harvested by women and used for medical treatments and local soap production.

3.5.3 Mozambique

The target to be set by the Government of Mozambique is 5% biodiesel in the diesel. This means that to achieve those targets 20 million litres of biodiesel (5% of 400 million litres diesel) is required.

There is large enthusiasm in Mozambique for the production of biodiesel, and many small projects have started with large policy support from the government. The state oil company Petromoc plans to produce a total of 185 million litres of biodiesel, and this will be more than enough to satisfy the requirements of the Mozambican market according to the target set [15].

3.5.4 Niger

The ethanol production potential is very low in Niger due to the absence of sugar cane production and low precipitation. However, there is particular interest to produce biodiesel from Jatropha oil. Initial calculations based on cost estimates indicate that biodiesel could compete with (fossil) diesel [10].

3.5.5 Tanzania

A private company supported by the government of Tanzania intended to apply for CDM greenhouse gas emission reduction credits with a project of biodiesel from Jatropha curcas oil. There are some efforts in Tanzania already directed towards promoting Jatropha plant as income generating activity in various areas of the country. Among these, more than 21,000 Jatropha plants have been distributed and planted in the project areas (Monduli, Mto wa Mbu, Selela, Longido and Namanga in Arusha Region).

The project will produce the biodiesel from Jatropha seeds and use it as fuel alternative to diesel fuel. The use of biodiesel as an alternative to petrol-diesel fuel should lead to lower diesel consumption and reduced CO_2 emissions. Moreover, the fuel will reduce country over-dependence on imported diesel. The project focuses on producing Jatropha oil and installing a biodiesel plant with capacity of producing on average 12,000 ton/year. To meet this objective the proposed project will be implemented in two phases. The first phase will involve establishing Jatropha farms of about 10,000 ha, and the second phase will involve installing oil pressing and low cost biodiesel processing plants, operating the plants and selling biodiesel.

3.5.6 Togo

Like in Niger, the private sector has particular interest to produce Jatropha oil as a source for biodiesel. Initial calculations based on cost estimates of the various production factors indicate that biodiesel could compete (5% lower prices) with fossil diesel. A point of attention remains nevertheless the competitive production of Jatropha seeds [10].

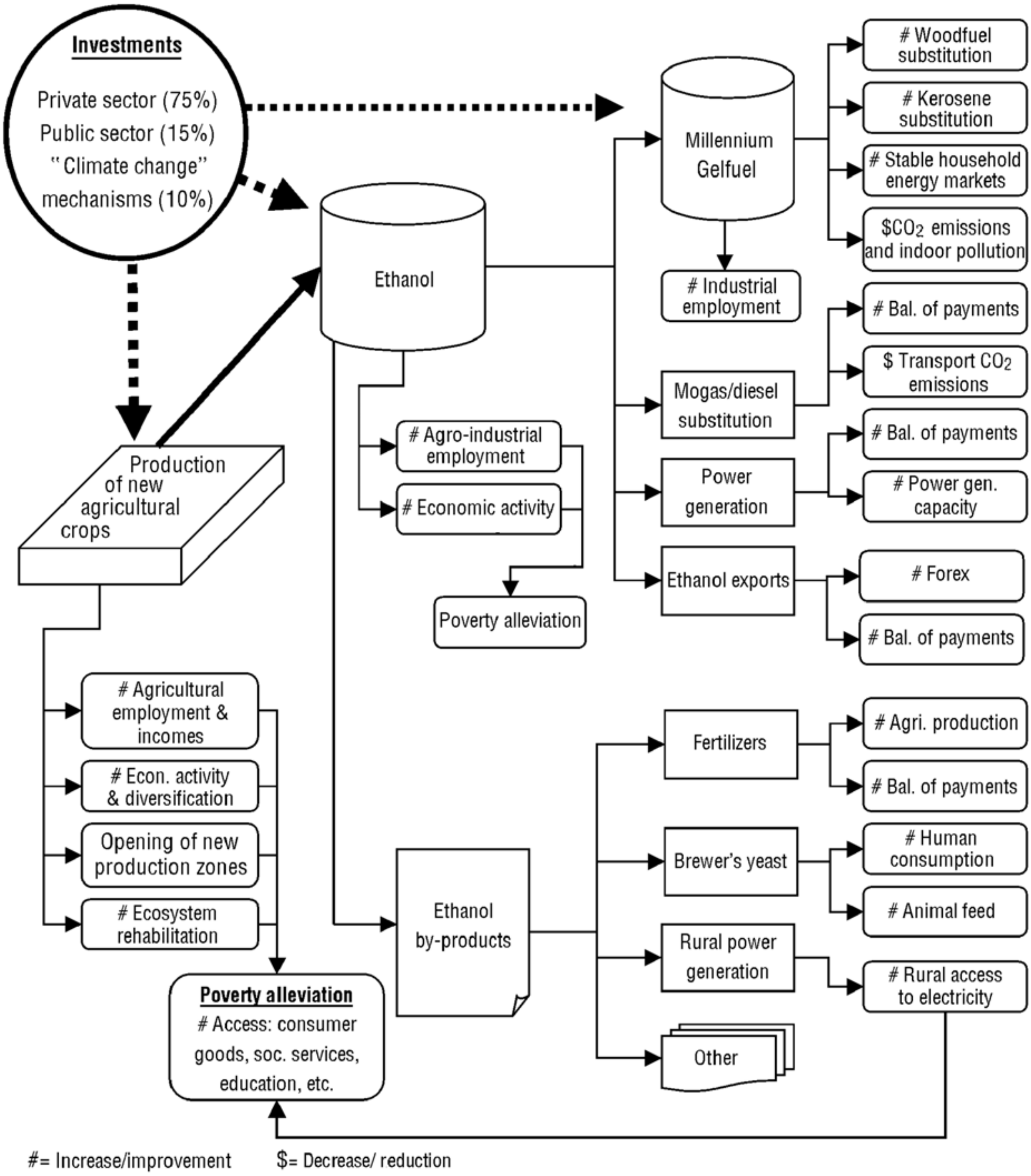
Chapter IV Socio-economic aspects

Despite many potential advantages, one must not take for granted that biofuels will automatically contribute to sustainable development. Biofuels activities are almost inevitably labour-, resource- and land-intensive undertakings. For example, labour requirements for producing biomass energy feedstock are considerably higher than for conventional capital-intensive forms of extracting fossil fuels like coal and oil, but this should not be a problem for countries with a largely unemployed and young population and which furthermore import fuels. Biofuels activities will therefore directly and keenly affect the communities in which they are located. One can envision best-case scenarios in which biofuels becomes major source of quality employment and provides a means through which energy services are made available widely in rural areas, while giving rise to environmental benefits such as carbon reductions, land restoration, and watershed protection. On the other hand, one can also envision worst-case scenarios in which biofuels leads to further consolidation of land holdings, competition for cropland, displacement of existing livelihoods, while incurring the environmental costs of decreased biodiversity and greater water stress.

Under adequate and socially responsible policy frameworks, a sustainable process of local rural economic growth and diversification would gradually develop with broad poverty alleviation impacts.

The "economic mechanisms" in operation here are: (1) linking the commercial demand for traditional and modern fuels with the existing local potential capacity (land, labour, water, knowledge, etc.) to produce alternative modern fuels; and (2) re-orienting the financial resource flows away from "commodity purchase" (energy imports) towards "capital investments" (biofuel production facilities) and "welfare" build-up (employment and income generation). While the depth and persistence of foreign exchange problems in most African countries have been linked to petroleum importation dependency, the Brazilian ProAlcool program is estimated to have leveraged US$ 48 billion in avoided hard currency expenditures on the basis of a US$ 5 billion investment [23]. The figure below highlights some of the relations existing between ethanol production and other socio-economic aspects.

Figure 1 – Ethanol: a sustainable engine for poverty alleviation [29]



In the previous chapters some of these issues have been briefly mentioned, here we will discuss these issues more thoroughly. When necessary a distinction will be made between alcohols and oils, otherwise the issues will be treated jointly.

4.1 Fuel security and price

Most developed countries use much more fossil fuels than they can extract from their territory, therefore becoming dependant upon foreign suppliers as a result. As such, this dependency has become a major cause of wars and leads to great volatility in stock markets, besides many human rights violations in certain oil-producing countries allied with the West. Thus the production of biofuels on their own territory, diversifies the supply base and increases the security of supply.

World market prices for conventional energy sources, in particular oil, are quite volatile. This poses great risks for the world's economic and political stability, with (sometimes) dramatic effects on energy-importing developing countries, even more than on developed countries. In this context, biofuels can help diversify energy supply and reduce the reliance on fossil fuel with impacts on energy security - i.e. the availability of energy at all times, in sufficient quantities and at affordable prices.

Developing countries and especially in Africa (besides for a number of exceptions such as, Saharan countries, Angola, Nigeria, Gabon, Cameroon, Congo, etc.) are particularly vulnerable because they are dependent from oil imports, and are often landlocked and due to their limited internal demand dependent from one supplier (country or company). Most of these countries have the potential to even become biofuels exporters and this would much improve their balance of payment and boost the economy. Some of these countries even have preferential import rates with the European Union and they could become its suppliers of biofuels.

The cost price of producing ethanol determines its attractiveness from a purely commercial point of view. This price is very favourable in the case of Brazil. Ethanol production costs vary between US$ 0.15 and 0,35 per litre [24]. In [25] is given that the production costs in Brazil are US$ 68/oil barrel equivalent, this translates in US$ 0.23/litre. In Brazil ethanol competes with gasoline if the oil price is above US$ 25 tot 30 per barrel [26], this means US$ 0.19 per litre oil, and this is not in contradiction with the numbers before as there is a factor of 1.5 to 2 between the cost of oil and that of gasoline. These costs have to be compared with the cost of producing gasoline, of around US$ 0.3/litre.

However, the use of ethanol from sugar cane puts pressure on the world price of raw sugar, which has risen 80 percent during 2005. Sugar sold at US$ 417 per ton in February 2006. As a result, the price of ethanol in Brazil has risen from US$ 0.25-0.28 per litre during the first half of 2005 to US$ 0.35-0.38 in the second half of 2005, and to US$ 0.58 per litre in April 2006 (US$ 92 per barrel of ethanol, or US$ 115-130 per barrel of gasoline equivalent). In response, the government of Brazil lowered the mandated quantity of ethanol in gasoline from 25 percent to 20 percent [27]

4.2 Job creation

One of the effects on the economy of biofuels is the creation of a large numbers of rural jobs in the agricultural sector, in the agro-industrial sector (crops, distillation, processing of by-products), in the commercialisation of new market commodities (oil, ethanol, gelfuel) and in new products (energy, fertilizers, animal feed, etc.) with guaranteed market absorption. The employment would drive up rural incomes, improving access to health and education, and to other commercial modern energy services.

As an example the Brazilian sugarcane sector was responsible in 2004 for 700,000 jobs and around 3.5 million indirect jobs, corresponding to the production of 350 million tonnes of cane [25]. The current ratio of jobs created per unit of energy produced is much higher than for other energy sources, if one takes the oil industry as the baseline (oil = 1) then hydroelectric power creates 3, coal creates 4 and ethanol creates 152 jobs. Also, job generation in most other industries requires higher investments

Table 7 – Cost of creation employment [24].

	1,000 US$/job
Ethanol / Agro-industry + industry	15
Consumer goods	44
Intermediate industry	70
Automotive Industry	91
Capital goods	98
Metallurgy	145
Chemistry/Petro-chemistry	220

For Jatropha there is less experience and surely not on the scale of the existing ethanol production. However, Jatropha has also a considerable potential for job creation, and if produced in smaller areas or in homesteads and processed locally will have a more dispersed job creation effect.

4.3 Land issues and ownership

In most African countries there is enough land available for agricultural production. What is not clear is what the actual status of the areas considered to have agricultural potential is: are these areas now forests, savannahs, deforested, marshes, etc. This should be seriously considered as it will be more difficult to get any kind of certification for the biofuels if one will clear large forest areas for biofuels production. In this respect the production of biodiesel from Jatropha or existing coconut plantations will have potentially less impact because Jatropha does not require good agricultural land and can be planted in marginal lands and coconut plantations exist all over the coastal areas and are owned very diffusely by a large number of families. The production of Palm Oil like in Malaysia is one example that should not be followed as large areas of tropical forests have been cleared for oil production. Similar objections would apply for the production of ethanol from corn in developing countries due to the agricultural grade land it requires and the multiple inputs (fertilisers, pesticides, water, etc.).

In establishing large sugarcane estates there is the danger that small farmers will be pushed away from their lands, when big land concessions are given. In most countries and by law these large companies have to negotiate compensations for displaced farmers, but we know that this works well in theory, but the negotiation weight of small farmers and large companies is very different in practice.

4.4 Agriculture and land-use

Nearly half the world's poorest people live on marginal lands with the number expected to increase from 500 million to 800 million by 2020. These areas are by definition isolated and fragile, with soils susceptible to erosion and subjected to environmental stresses of deforestation, prolonged droughts, and decreasing soil and ground water. Plants species like Jatropha that can grow on lands not usually attractive for agriculture and supply raw material for industry, fuels for basic energy services and improve environment are therefore an obvious choice that needs to be assessed carefully and comprehensively.

Jatropha is not browsed, for its leaves and stems are toxic to animals, but after treatment, the seeds or seed cake could be used as an animal feed. Being rich in nitrogen, the seed cake is an excellent source of plant nutrients. Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has honey production potential. Like all trees, Jatropha removes carbon from the atmosphere, stores it in the woody tissues and assists in the build up of soil carbon [28].

4.5 The food versus fuel discussion

Biofuels can require a lot of land. One hectare could yield a quantity of ethanol that would roughly match the annual fuel consumption of four standard passenger cars. (i.e., 65 tonnes of cane per hectare per year and 75 litres of ethanol per tonne of cane approximately match the needs of four cars getting 12 litres per 100 km and travelling 12,000 km per year.) [26].

Biofuels production can increase the demand for agricultural inputs such as land and water, and this can jeopardise the production of foodstuffs, the so-called *"fuel versus food"* dilemma. A number of studies done in past years under the RPTES programme shows that the scaling-up of agricultural crops for biofuels can *be done without competing with food production* and without resulting in incremental forest land clearing. The estimates of the land area that would be required in Africa to set up *new plantations* (sugar cane, sweet sorghum, cassava, maize and sweet potatoes) equivalent to scaling-up crop production by 25 % and 50 % over actual 2000-01 harvest levels, show that even a 50 % scale-up would be possible without necessarily creating food/energy trade-off problems [29]. These scenarios are based on a "constrained projection" food security assessment methodology where up-scaling potential is strictly subject to the availability of "suitable" and "very suitable" idle land and other necessary production inputs.

In some places it may well be a problem: while fuel-food competition can be avoided by growing energy crops on marginal or "waste" land, doing so may mean high production inputs and costs to achieve financially-acceptable crop yields. Conversely, the best net returns and profits for energy crop producers may arise from using good quality, though expensive, crop land. Given these divergent situations, it is crucial that biofuel crop projects and programs base their design and site selection on sound, local information about the relative merits of biofuel crops and alternative crop production – and do so using a broad, rural development-based perspective. This process will often require a careful consideration, for fuel and alternative crops, of the trade-offs between land quality, land cost and crop yield, in the context of local development needs.

Furthermore, not all production of biofuels would require the use of land. The situation of the sugar production industries in Africa show that there is a huge surplus of molasses that do not find their way to the market, even though they are a valuable food for animals, and that could be utilised (at least to start) for ethanol production. Molasses are often dumped into rivers, stored in artificial lakes at the sugar factory, or used to control dust in the roads around the sugar factory. The problem is that the cost of transportation of the molasses for other uses far away from the sugar factory makes them too expensive. Nevertheless, adequate policy and regulatory frameworks would be required to ensure that no conflicts -if any- could arise. But this is exactly an area where international agency policy support and implementation monitoring and evaluation would be extremely valuable. Also and this is certainly true in the African context it will be hardly justifiable to use a food grain as a feedstock of the fuel industry, because corn requires highly productive land that is scarce in most countries in Africa.

Hunger is more often a function of poverty and of problems in the distribution systems and/or market chains, than a problem of lack of food, land or other agricultural inputs. Low agricultural yields are a function of poor soils and rain regimes and limited fertilization and soil nutrients reconstitution practices. About a billion people now do not have enough food to meet basic daily needs, but that is not because there is not enough food. There is more food per capita now than there was ever been before, enough to provide at least 4.3 pounds of food per person a day: two and a half pounds of grain, beans and nuts, about a pound of fruits and vegetables, and nearly another pound of meat, milk and eggs [30].

People starve because they are victims of an inequitable economic system, not because they are victims of scarcity and overpopulation.

In Brazil the largest producer of ethanol in the world, the facts do not support that there are negative impacts of the production of biofuels on the production of food (quoted from [31]): The food shortages and price increases that Brazil suffered a few years ago, were blamed on the ProAlcool programme. However, a closer examination does not support the view that ethanol production has adversely affected food production since Brazil is one of the world's largest exporters of agricultural commodities and agricultural production has kept ahead of population growth: in 1976 the production of cereals was 416 kg per capita, and in 1987 -- 418 kg per capita. Of the 55 million ha of land area devoted to primary food crops, only 4.1 million ha (7.5 per cent) was used for sugarcane, which represents only 0.6 per cent of the total area registered for economic use (or 0.3 per cent of Brazil's total area). Of this, only 1.7 million ha was used for ethanol production, so competition between food and crops is not significant. Food shortages and price increases in Brazil have resulted from a combination of policies which were biased towards commodity export crops and large acreage increases of such crops, hyper-inflation, currency devaluation, price control of domestic foodstuffs, etc. Within this reality, any negative effects that ethanol production might have had should be considered as part of the overall problem, not the problem.

Recently, the increase of the price of tortillas in Mexico has been in the news [32] and it has been attributed to the increase of price of corn in the United States. Because of the subsidies to the USA corn farmers, they have historically overproduced and have practiced “price dumping” with the surplus corn in the global markets. The price dumping (either thorough the market or through “aid food donations”) has undercut developing countries’ producers and made them abandon corn production. Now that the USA is absorbing all of its corn production for ethanol there is a short-term deficit in the global food market. Given that situation and higher corn prices non-USA farmers – especially in developing countries -- can respond by increasing their production to previous historic levels. There is no shortage of land for corn cultivation and farmers will respond within one or two planting seasons to the new price incentives. Thus, the tortilla effect will - most probably - be short-lived.

The above mentioned problems are due to the fact that the increase of production capacity and product markets react slowly to changes, and will adapt to larger demands in the near future.

4.6 Energy supply in rural areas

The possibility to produce and use biofuels in rural areas is also closely linked to poverty reduction as an improved access to modern energy services will likely:

- Improve access to pumped drinking water.
- Reduce the time spent by women and children on basic survival activities (gathering firewood, fetching water, cooking, etc.).
- Allow lighting, enabling the use of educational media and communication in school and home study at night.
- Reduce indoor pollution caused by firewood use, together with a reduction of deforestation.
- Allow the introduction of mechanised systems for agriculture, processing and other productive activities.

With ethanol but especially with Jatropha oil (or any other oil produced locally) a true rural economy can develop: biofuels can be used for lighting, can be used for cooking, and can be used to drive a diesel for mechanical power (milling, pumping) and electricity generation.

Cooking

In most rural, and many urban and peri-urban areas of developing countries wood is still the main energy source. Steadily rising wood consumption for cooking purposes results in deforestation of large areas creating severe ecological, economical and sociological problems. In order to protect the environment it is urgently required to substitute the use of firewood for cooking purposes. Use of electricity or kerosene is limited mainly to urban areas due to high prices, shortages, uncertain supply, and difficult distribution of these energy sources especially in remote areas. Introduction of fuel-efficient stoves can significantly reduce the firewood consumption. However, the decrease in consumption will soon be compensated by the fast growing population. The use of solar cookers and the utilization of biogas are still limited due to technical and handling problems. Ethanol, gelfuel and plant oils are a promising alternative energy source offering a variety of economical and ecological advantages.

Gelfuel can be used in very simple stoves, which can be made out of recycled metal cans and cost few dollars. These burners can be put inside other existing (improved) stove or mounted in an appropriate frame. Straight ethanol burners also exist but they are more sophisticated and somewhat costlier, however, they permit the use of the cheaper (than gelfuel) ethanol in a controlled and safe way.

Concerning Jatropha, and assuming an extraction rate of 30 % and an efficiency of the plant oil cooking stove of 50 %, the total cooking energy for one person could be covered by 55 litre of Jatropha oil per year. In Mali, this quantity can be produced on an area of about 0.06 ha or with a hedge of 175 m in length. The oil of Jatropha is currently used locally, mostly for the manufacturing of soap, for medical purposes and, experimentally, as a substitute for diesel engine fuel. Use as cooking fuel would enhance the possible applications [33].

Due to the low ignition points of about 50 °C fossil fuels can easily be ignited with a match. Plant oils can be used in modified kerosene pressure stoves, which are available in most developing countries. Due to the high ignition point of plant oils ranging from 300 to 350 °C these fuels have to be pre-heated in order to be vaporized. Furthermore the viscosity of plant oils is likewise considerably higher than the viscosity of kerosene and diesel oil. To avoid clogging of tubes and nozzle the viscosity of plant oils has to be decreased. Since viscosity reduces with higher temperature pre-heating of plant oil in the cooker has to be considered as well as possible admixture of additives.

Lighting

PPO can also be used to produce light in very simple lamps that can be manufactured locally. This would allow for the substitution of kerosene that has often to be transported over large distances, is expensive, the supply unreliable, and has to be imported in most African countries.

Mechanical power and electricity

PPO and/or biodiesel can also be used as the prime mover for diesel generators. The old diesel motors available in many isolated places in Africa can take this PPO directly after pressing and filtration without the more complicated esterification step. In Mali plant oils have been used in the multifunctional platforms being promoted under a UNDP programme.

The availability of an un-expensive and reliable source of mechanical power and electricity is one of the preconditions for attaining economic development and to be able to develop productive uses in rural economies.

4.7 Environmental issues

We will here look at other environmental aspects that have not been dealt in previous chapters. Biofuels activities are intrinsically linked to the environment because they are a land- and resource-intensive undertaking. They have a range of potential environmental benefits that biomass-related policies should seek to encourage through incentives as well as adverse impacts that policies should aim to prevent though regulations.

Water: Biofuel crops affect water resources in several ways. Biofuel crops can very positively affect hydrology, by re-vegetation of degraded areas and thereby improving ground water replenishment and surface water health. Biofuels growth increases the use of agricultural inputs, however, they can increase chemical loadings to freshwater. They can also contribute a large water demand if fast growing energy crops are grown or biofuels facilities are operated with large water demands.

Forests, habitat, and biodiversity: Tremendous benefit could result from the integration of biofuel crops with the restoration of degraded land. Biodiversity – ranging from the soil organisms that keep soil healthy, to the plants on the soil, to the animals living among the plants – could benefit from judicious planting of plant species that simultaneously provide environmental services while serving as an energy feedstock. **It is vitally important that measures are put in place to ensure that the environmental benefits are not sacrificed for the sake of maximising yields of biofuel feedstocks,** which will be the case if optimising biofuels profits is not tempered by environmental and social guidelines that protect biodiversity and human habitat. Participatory methods of resource management will help to safeguard this balance.

Waste disposal regulations and practices: Waste disposal regulations and practices affect the incentives for creating and expanding biofuels systems. In considering formal regulatory options, it is important to consider informal resource management practices, which sometimes evolve into more environmentally sound practices without the need to resort to bureaucratic regulations. Indeed, such regulations might in fact be a hindrance where they are inconsistent with locally respected common property regimes. Even best-intentioned environmental regulations might not improve resource management, if their enforcement proves prohibitively costly.

The example from Brazil is important in this context: In the early days of the ProAlcool programme in Brazil, some forests and savannahs have been destroyed, but this was soon halted. The following paragraphs which give examples of good environmental practices in Brazil are adapted from [31].

The overall production cycle of biofuels in Brazil, including the agricultural and industrial processes for alcohol production, is sustainable. The sustainability of ethanol production has increased significantly and in the São Paulo State (responsible for more than 60 per cent of the Brazilian ethanol production), strict environmental legislation is applied in any agricultural and industrial sector, including sugarcane production. Specific environmental requirements include:

- The use of fertilisers in sugarcane fields is controlled, so that hazardous chemicals can be replaced with the by-products of industrial production (vinasse and filter cake). This reduces the use of chemicals and avoids pollution of ground water and rivers.
- In recent years, the genetic development of sugarcane species has advanced and has been funded by producers. These developments have resulted in the reduction in the use of pesticides and their environmental impacts; an increase of sugar content; the development of disease-resistant species; better adaptation to different soils; and the extension of the crushing season.
- Sugarcane plantations have expanded mainly in areas previously used for cattle. But have remained almost constant for the past 35 years. Environmental legislation specifically specifies that it is forbidden to engage in any type of deforestation. In São Paulo State, for example, each agricultural producer must guarantee a preserved area (corresponding to 20 per cent of the total area planted with sugarcane as a natural reserve to guarantee the local biodiversity). Additionally, isolated trees cannot be cut without permits from the state environmental agencies.
- Environmental regulations also require that green cane harvesting, i.e., harvesting without previous field burning is gradually introduced if topographic conditions permit this. Green cane harvesting will allow the recovery of sugarcane trash (leaves and the tips of the plant), and a deep increase on biomass availability for energy production in industrial process.
- The industrial processes linked to alcohol production must adhere to the environmental requirements related to atmospheric and liquid effluents, among other impacts. Energy needs also have to be met from the use of sugarcane bagasse (a by-product of sugarcane crushing). This explains why fossil fuel consumption in the overall process is extremely low and the energy balance is highly positive (11 units of energy to 1 unit of energy of fossil origin).

4.8 Gender

The gender impact can also be important as biofuels are clean burning fuels for cooking, lighting and possibly refrigeration, and can have positive health effects because of reducing/avoiding the exposure of women and children to high levels of smoke and particulates resulting form the combustion of charcoal and particularly fuelwood, effects which have been well studied and documented. According to the World health Organisation in Sub-Saharan Africa alone 396,000 deaths occur due to expose to indoor smoke [34]

Also the use of biofuels can alleviate in some cases the burden of collecting fuel (which even in small towns happens), reducing the amount of time for cooking and for cleaning pots, reducing the number of firewood burns, etc. Biofuels are certainly safer and cleaner than kerosene, which is the primary inter-fuel substitution step away from traditional woodfuels for low income households in developing countries.

4.9 Bio-trade principles

Based on the experience of national programmes in the implementation of their principles and criteria and the different contexts in which they have been applied, a general set of bio-trade principles has been defined trough a joint process carried out by UNCTAD and the National BioTrade Programmes. The following principles have been agreed upon and adhered by the BioTrade initiative, its programmes and partners:

1. Conservation of biodiversity.
2. Sustainable use of biodiversity.
3. Equitable sharing of benefits derived from the use of biodiversity.
4. Socio-economic sustainability (management, production and markets).
5. Compliance with national and international legislation and agreements.
6. Respect for the rights of actors involved in BioTrade activities.
7. Clarity about land tenure, use and access to natural resources and knowledge.

4.10 Additional issues

In many African countries there is an enormous political thrust to motivate people to plant Jatropha, but the problem is often that there are not yet processing facilities, or a structure that guarantees the purchase of the product from the farmers, neither there is any idea for what price. This can lead to a lot of frustration and discredit for the biodiesel production chain if in the near future people will not be able to sell their products.

Jatropha is poisonous if eaten in large quantities, and often there is a lot of negative publicity about this. The Jatropha plant has several medicinal properties and is used as such, but like anything else if taken in large quantities can be damaging. However, Jatropha has a terrible taste, so bad that no animals eat it, even not goats. To eat the quantities of the plant needed to be poisoned, a child must be very tough. In countries where the plant is widespread (used as fences around farms, to protect them from animals and also against wind erosion), there are no records of deaths caused by it.

Cassava can also be poisonous (every year people die in Africa because of this) but it is still widely accepted as a staple food.

One example of vested interests is South Africa where there is large negative publicity about Jatropha: it is poisonous (true), it is not an indigenous plant (true), and will overcrowd local species (not true). It seems that most of this information that is published in newspapers is being financed by the powerful soybean industry which is the main producer of ethanol in South Africa.

References

[1] Beyond Petroleum and towards a biomass-based sustainable energy future. Sergio C. Trindade.

[2] Wikipedia

[3] Biofuels: At what cost? Government support for ethanol and biodiesel in the united States. Doug Koplow. Prepared for The Global Subsidies Initiative (GSI) of the International Institute for Sustainable Development (IISD), Geneva, Switzerland. October 2006.

[4] Tax incentives for ethanol and petroleum, at www.ethanol.org/pdfs/oilincentive study.pdf

[5] www.english.aljazeera.net

[6] WB Project Idea Note, 2006

[7] www.gvep.org/content/general/detail/12479

[8] Assessment of the Potential to Introduce the Local Production and Marketing of "Millennium Gelfuel" in Ethiopia as a Renewable Household Cooking Fuel, Sultan Tilimo and Mekonnen Kassa, December 2001, updated 2004.

[9] Le quotidian, Dakar, 26 July 2006

[10] Étude sur le Développement de la filière «Ethanol / Gelfuel» comme énergie de cuisson dans l'espace UEMOA, UEMOA, Draft Report, September 2006.

[11] Feasibility Study for the Production and Use of biofuel in the SADC Region. Tobias Takavarasha, Jai Uppal, Hamimu Hongo, Gabarone, August 2005.

[12] Harnessing sweet sorghum for bioenergy in Zambia, Emmanuel Matsika, Francis D. Yamba and Kalaluka Munyinda, in Renewable Energy for Development, December 2006, Vol. 19, No. 3.

[13] WB – RPTES document , no author, 2004.

[14] Ethanol and Gelfuel – Clean renewable cooking fuels for poverty alleviation in Africa. Júlio de Castro. May 2005.

[15] Biofuels Initiatives in Mozambique. Júlio de Castro, January 2007.

[16] WB – RPTES document , no author, 2004

[17] CRC Handbook of chemistry and physics. D.R. Lide and H.P.R. Frederikse. CRC Press, Boca Raton, USA. 1995.

[18] The Jatropha Manual - A guide to the integrated exploitation of the Jatropha plant in Zambia. R.K. Henning. Produced for GTZ.

[19] www.jatropha.de

[20] Handbook on Jatropha. FACT Foundation, first draft March 2006.

[21] Use of Jatropha curcas L.: A household perspective and its contribution to rural employment creation - Experiences of the Jatropha Project in Mali, West Africa, 1987 to 1997. R.K. Henning. Presentation at the "Regional Workshop on the Potential of Jatropha Curcas in Rural Development & Environmental Protection", Harare, Zimbabwe, May 1998.

[22] Potential for Biodiesel for Transport in Developing Countries. M. Kojima and T. Johnson. ESMAP, October 2005.

[23] The Brazilian ethanol experience as fuel for transportation. Arnaldo Vieira de Carvalho. Presentation at Energy Week 2003, Washington.

[24] The Brazilian energy initiative - support report, by José Goldemberg, Paper Presented at the Johannesburg 2002 World Summit for Sustainable Development.

[25] Ethanol learning curve - the Brazilian experience, by Goldemberg et al., Biomass and Bioenergy, Vol. 26/3, pp. 301-304.

[26] Advancing Bioenergy for Sustainable Development, Rols for policymakers and entrepreneurs. S. Kartha, G. Leach, S.C. Rajan, ESMAP Draft report, October 2004.

[27] WB Clean Energy Development Investment Framework.

[28] The Potential of *Jatropha curcas* in Rural Development and Environment Protection – An Exploration. Workshop paper in Zimbabwe, Harare, 13-15 May 1998.

[29] Ethanol and Gelfuel: clean renewable cooking fuels for poverty alleviation in Africa. Boris E. Utria. In Energy for Sustainable Development, Vol. VIII, No. 3, September 2004.

[30] http://journeytoforever.org/biofuel_food.html

[31] Advancing bioenergy for sustainable development. Stockholm Environmental Institute. October 2004.

[32] De Volkskrant, March 10, 2007.

[33] Plant Oil-based Cooking Stove – A Technology Update. W. Mühlbauer, A. Esper, E. Stumpf and R. Baumann. Institute for Agricultural Engineering in the Tropics and Subtropics, Hohenheim University, Stuttgart, Germany

[34] Fuel for life, Household Energy and Health. WHO 2006

[35] Biofuels for transportation: global potential and implications for sustainable agriculture and energy in the 21st century. Prepared by the Worldwatch Institute for the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), in cooperation with the Agency for Technical Cooperation (GTZ) and the Agency of Renewable Resours (FNR), Washington, D.C., June 7, 2006

[36] Fachlicher Zwischenbericht zum Projekt: Produktion und Nutzung von Pflanzenöl als Kraftstoff; unpublished project report. R.K. Henning. Projet Pourghère, GTZ, 1996

[37] Biodiesel fuel production for transportation in Tanzania. no author, no date.

[38] An Assessment of the Biofuels Industry in India. Joseph B. Gonsalves. UNCTAD (United Nations Conference on Trade and Development), 2006.

[39] Energy and GHG emissions results of ethanol. Michael Wang. Argonne National Laboratory, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

[40] A blueprint for Green Energy in the Americas. Garten Rothkopf. For the Inter-American Development Bank. 2006.