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AN INFORMAL NOTE ON

JATROPHA-BASED BIOENERGY AND CARBON FINANCE OPPORTUNITIES IN

KENYA

For the Ministry of Environment and Natural Resources and Ministry of Energy, Supported by the World Bank

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ACKNOWLEDGEMENTS

This report was prepared by Jochen Statz (consultant) under the supervision of Enos E. Esikuri (Senior Environmental Specialist, Environment Department, The World Bank). The study was made possible through a grant from the World Bank's Sustainable Development Network Vice President's Challenge Fund meant to enhance integration across sectors. The team would like to thank Kathy Sierra, Vice President, Sustainable Development Network, for this initiative. Additional financial support for this work was provided by the Carbon Finance Unit of the World Bank.

Editorial and publishing support were provided by Jim Cantrell (Communications Analyst, ENV) and Robert Livernash (consultant).

1 SUMMARY

There is a strong interest in *Jatropha*-based biofuel production in Kenya. Highly degraded land is abundant, is un-utilized/under-utilized and suited for *Jatropha*, and is not suitable for food crop production. Considering the high unemployment in the country, there is a great demand for such activities.

The World Bank conducted a feasibility study to promote *Jatropha*-based biofuel production in Kenya. Possible partners should be linked with this initiative, which can serve as a pilot planting scheme. This will require a strong extension agency to introduce improved Jatropha seeds and the requisite management technology.

Jatropha production potential in Kenya is unclear, as is the market price for *Jatropha* oil. Studies from India indicate that seeds may fetch a price of US$0.2/kg. Based on studies in India, seed production potential is between 0.5 and 12 t/ha/year. This large bandwidth reflects different site conditions and varieties. It also demonstrates that the production risk is quite high.

The market risk is also considerable, unless producers receive price and delivery guarantees or the government introduces a biofuel policy requiring petroleum companies to sell only blended D5 or D10 diesel in the future (that is, diesel blended with 5 to 10 percent biodiesel). Such a policy successfully started biofuel production in Europe. It is also possible to use straight *Jatropha* oil to operate engines if they are modified with a *Jatropha* oil pre-heating kit. The German company Elsbett, for example, sells tractor adaptation-kits for about €400.

In summary, for a sustainable *Jatropha*-based biodiesel project to be realized, a business and marketing plan has to be developed before the design of the carbon finance component can be developed. Carbon finance can only contribute to making a project viable; it cannot be used to generate the main cash flow.

2 BEST PRACTICES FOR JATROPHA FEEDSTOCK PRODUCTION

2.1 *Jatropha curcas*

Jatropha curcas is a drought-resistant perennial plant belonging to the Euphobiaceae family. It is related to other important cultivated plants like rubber and castor. The genus *Jatropha* contains approximately 170 known species. *Jatropha curcas* is native to Central America and Mexico (Heller 1996).

From the Caribbean, *Jatropha* was distributed by Portuguese traders via the Cape Verde Islands to Africa and Asia (Heller 1996). In the 16th Century, Jatropha was introduced to India (Shanker and Dhyani 2006). In China it is known that it was introduced more than 200 years ago.

Jatropha is widely used for fencing. *Jatropha curcas* seeds and the plant are toxic and therefore well-suited to keep livestock at distance. Only a few *Jatropha* species in Mexico are not toxic. Cape Verde was a main *Jatropha* seed producer in the first half of the 19th century. The oil was exported to Lisbon and Marseille, where it was pressed and used for soap production.

The plant is of Latin American origin and is now widespread throughout arid and semiarid tropical regions of the world. As member of the Euphorbiaceae family, *Jatropha* is a drought-resistant perennial. It lives up to 50 years and grows on marginal soils. A close relative of the castor plant, its oil has the same medical properties. *Jatropha* seeds contain about 35 percent of non-edible oil. The production of seeds is about 0.8 kg per meter of hedge per year, with an oil yield of 0.17 liters (Henning 1994).

In western Africa, *Jatropha* curcas is generally well-known among the rural communities 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 (Henning 1992). Traditionally, the seeds were harvested by women and used for medical treatments and local soap production. As early as the 1930s, the oil's potential as a fuel source was recognized in the region (Kone 1988).

Currently, it can be used to substitute for the "gazoil" mixture used in Indian-type diesel engines, which drive grain mills and water pumps in rural areas of Africa. The high-quality oil extracted by engine-driven expellers or by manual Bielenberg ram presses or the sediment of the oil purification process may be used for larger scale soap making in rural areas, giving local women the chance to gain additional income and thus strengthen their economic position. Press cake—another extraction by-product—can be used as a high-grade organic fertilizer.

Jatropha cultivation promotes four main aspects of development, which combine to help assure a sustainable way of life for village farmers and the land that supports them: (1) erosion control and soil improvement; (2) promotion of women enterprises; (3) poverty reduction; and (4) renewable energy.

2.2 Seed sourcing and nursery operations

2.2.1 Seedlings versus cuttings

In China, the Forestry Department highly recommends using *Jatropha* seedlings, mainly because of higher survival rates and the improved rooting patterns compared to cuttings. In India, studies suggest that seedlings are more drought-resistant than cuttings and therefore the first choice for *Jatropha* afforestation in dry lands.

Cuttings are only recommended to control the genetic material and if rainfall is sufficient to allow the establishment of the root systems. Heller (1996) mentioned that seedlings have lower yields in the first year, but usually higher yields in later years and therefore are highly recommended. It was also mentioned that cuttings produce flowers earlier than seedlings. However, improved plants from seeds also produce flowers after 7 months (pers. communication, Prof. Xu Jihong).

The picture below shows rooting patterns of seedlings and cuttings. Seedlings compared to cuttings produce a healthy tap root, enabling the plant to access groundwater. The main advantage of cuttings is that high yielding trees can be propagated with the same genetic material.

Rooting patterns of cuttings and seedlings (Source: Jains Ltd, India).

2.2.2 Seedling production

Commercial *Jatropha* seedling production has not yet started in Kenya. Farmers in Kenya starting large-scale *Jatropha* plantations would have to build on documented experience in Asian countries, mainly China and India. Existing knowledge from the Kenya flower industry also could be useful. However, it is probably more practical and beneficial to engage in *Jatropha* production via small scale rural farmers rather than plantations.

Jatropha seeds germinate after about 10 days. Ginwal et al. (2005) mention survival rates of 57 to 70 percent. In an experiment conducted by Heller (1996), direct seeding showed significantly lower survival rates than seeding in polyethylene bags. As discussed later, mycorrhiza-inoculated soil can increase germination rates from 50 percent to 95 percent.

Research on other tree species found that early germination indicates that plant vitality is high and late germination that plants are weak and will be weak throughout their lifespan. Therefore, plants that have not germinated beyond a certain time threshold should not be considered any further and should probably be replaced.

In India, seedlings are kept three months in a nursery before they are planted in the field. After six months, they have already reached a height between 40 and 60 cm. In Honghe, China, plants are kept six months in the nursery (pers. communication, Mr. Li Peng). Improved nursery technology will reduce the production period in the nursery.

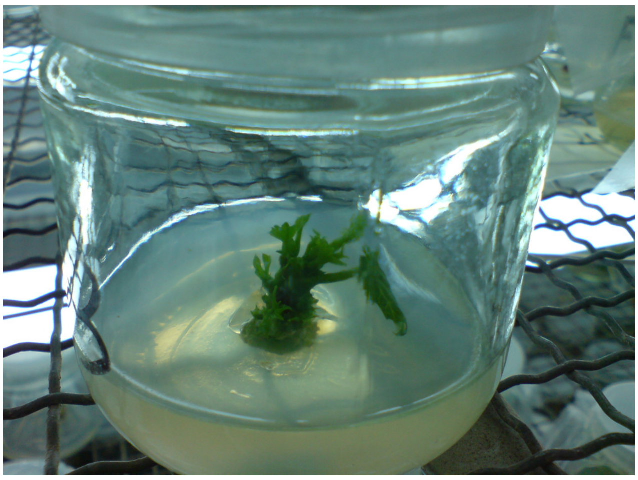
For planting in very harsh site conditions in South Africa, super absorbent soil conditioner such as AQUA-SOIL™ is recommended to establish *Jatropha* plantations. This blend of nutrients and potassium-based copolymers stores water and nutrients, which are slowly released on demand to the plant. The super-absorbent polymer contained in Aqua-Soil can, depending on conditions, absorb up to 300 times its volume in water (1g = 300ml).

Jatropha cutting nursery in Yunnan (Prof. Xu Jihong)

Jatropha is a cross-pollinating plant; genetic improvement programs must therefore be based on populations of superior plants. Populations can be improved using additive genetic variations based on the establishment of seed orchids (Henning, 1996). Within the last two years, a few institutions have selected wild varieties and have set up seed improvement trials, but improved varieties on a commercial scale are not yet available. It is possible to import high quality seeds from countries such as Mali or India.

2.2.3 Tissue culture propagation

So far, no commercial *Jatropha* tissue culture production is in place in Kenya. Existing tissue culture know-how from the flower sector could be applied. The price at which *Jatropha* plants could be produced at a commercial scale yet has to be established.



Tissue culture Jatropha plant (Prof. Xu Jihong).

Tissue culture plants can reach a height of 20 cm after 1 month. Plants are ready to be planted into the field after one month, but for commercial plantations using older plants (2–3 months) is recommended.

ADITYA BIO-TECH LAB AND RESEARCH PVT.LTD, a leading Indian biotechnology firm, has registered a patent on tissue culture propagation already. Dr. Sanket Thakur Kumar, the company's senior researcher, summarized the tissue culture research results of the past two years (Box 1).

Box 1. Findings from research on *jatropha* tissue culture
1. Auxiliary buds of fresh shoots are ideal for culture initiation.
2. The best periods for culture establishment are March–April and October–November.
3. A combination of BAP (1 mg/l), adenine sulphate (10 mg/l), and citric acid (30 mg/l) has proven to be suitable on MS medium for shoot multiplication, elongation, and shoot buds induction. Necrosis of leaves and entire tissue mass is still a challenge. It requires antioxidants and more growth regulators to control it.
4. Elongated shoots resulted in rooting on MS medium supplemented with IAA & IBA. However, rooting success was limited.
5. The rate of shoot multiplication and elongation was slower as compared to other species; therefore more efforts are needed to accelerate the growth.
6. Callus formation was a problem in multiple-shoot cultures; this needs to be restricted for higher shoot multiplication.
7. Survival of TC-rooted plants in greenhouses is a problem. The mortality percentage is very high. More research is needed to solve this problem.

Research results on jatropha tissue culture

2.3 Land Preparation

In China and India, *Jatropha* is only planted on land with a minimum soil depth of 45 cm. The standard land preparation method is to slash and burn and to plant the trees early in the rainy season. However, burning does not seem to be always necessary. Fire-free land preparation will reduce land preparation costs and will increase soil fertility, water holding capacity, and the soil fauna (pers. communication, Prof. Xu Jihong).

Planting pits are prepared with a depth, width, and length of 45 cm. After planting, they are covered with a mix of loose soil and fertilizer. However, on good soil it is sufficient to dig a hole of 15 cm depth for the plant and to fix the plant by manually compacting the soil. The latter procedure is much more cost efficient; about 1 villager can plant 0.05–0.09 ha per hour.

2.4 Maintenance

Jatropha trees have to be managed similar to fruit trees. In order to produce a high yield of fruit, the distance between individual plants must be sufficient to provide enough sunlight for lower branches. The following sections describe improved management procedures, common pests and diseases, and biological control methods from India.

2.4.1 Mycorrhized *Jatropha* plants

In China, *Jatropha* mycorrhiza research has just started and mycorrhiza-treated *Jatropha* plants are currently not available. However, TERI in India has produced mycorrhized *Jatropha* plants across the country in seven different agro-climatic zones. Some of the benefits of *Jatropha* plants with mycorrhiza compared to conventional cloned material are listed in Box 2.

Box 2. Advantages of *Jatropha* plant with mycorrhiza
• The germination rate can be increased from 50 percent to 95 percent with Mycorrhiza. • Plants set fruits after seven months with Mycorrhiza, compared to 1 year without Mycorrhiza.
• Yields will increase by 20 to 30 percent with mycorrhiza inoculation compared to noninoculated plants.

Source: see http://www.teriin.org/tech_jatropha.php

Considering these promising results in India, similar benefits can be expected in Kenya, if yields can be sustained.

2.4.2 Spacing

Currently the recommended spacing of the Forestry Department in China is 1,650 to 1,800 trees per ha, but this seems to be too high to achieve high yields, according to Chinese experts. Prof. Xu Jihong recommends planting 1,200 to 1,500 trees/ha (pers. communication).

2.4.3 Pruning

For optimal seed production, side-shoot pruning is highly recommended in India. The *Jatropha* plant should be cut back to 30 to 40 cm at the onset of the second rainy season to stimulate intensive branching (Fact 2006). At the third rainy season, two-thirds of the side branches should be cut to stimulate the development of secondary branches. Between 10 and 14 primary side branches seem to be the optimal amount. Further pruning is recommended, but it remains unclear which procedures provide the highest yield. Trees should be kept at a height of 2 m.

2.5 Pests and diseases

Information is limited on *Jatropha* pests and diseases. Some research has been done in southwestern Yunnan Province in China. Table 1 sums up results from a study conducted in the region. The study identifies six different insects that attack wild *Jatropha* plants in Yunnan. While conditions in Kenya differ clearly from those in China, the study proves that Jatropha is indeed prone to insect attacks that have to be known and understood before advocating the large scale cultivation of the species in Kenya.

Table 1. Research results on *jatropha* tissue culture

LATIN NAME	MAIN SYMPTOM
Carposinidae, current fruit moths	Larva destroy fruits, shoots, or stems
Gryllulus	Damage to roots, stems, leaves, fruits, and seedlings
Scutelleridae	Suck juices from twigs, shoots, young leaves, and fruits
Macrphominaphaseolina(tossi) G.Goid	Brown spots appear on the bottom of seedlings, then the phloem is rotted, and seedlings are withered
Erysiphe graminis D.Cf.sp. tritici E.Marchal.	Little yellow spots appear on the leaves, and then are enlarged to rounded or elliptical spots with white powdery mildew on the surface of the leaves
Phyllostcta sp	Round or unregulated spot, then parts die, and sometimes holes appear

Tab. Common pests recorded on Jatropha in Yunnan province (KIB working paper)

Galls often attack *Jatropha* trees in China. They can be very harmful because they reduce plant growth and related seed production.

In India, Shanker and Dhyani (2006), working at the National Research Centre for Agroforestry, published an overview of known insects that attack *Jatropha*. The results of the overview are presented below.

Contrary to popular belief that toxicity and insecticidal properties of *Jatropha* are a sufficient deterrent for insects that cause economic damage in plantations, several groups of insects have overcome this barrier. Particularly noteworthy is the insect order *Heteroptera*, which has at least 15 species in Nicaragua. These insects can extract nutrients from *Jatropha*.[1] The key pest in Nicaragua is *Pachycoris klugii* (Scutellaridae: Heteroptera), occurring at a density of 1,234 to 3,455 insects per hectare.[2] The insect that caused maximum damage proved to be the seed-feeding Scutelleridae, *Agonosoma trilineatum*.[3]

The crop is projected to have less pest damage and hence minimum requirements for plant protection. In India, when *Jatropha* is grown in continuous stretches as a monocrop, it is attacked by two pests that are emerging as a major problem in *Jatropha* cultivation.

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[1] P.C. Grimm and J.M.Maes. 1997. *Nicaraguense Entomol.*, 39: 13–26.

[2] C. Grimm. 1997. *Manejo Integrado Plagas*. 42: 23–30.

[3] K. Smith and T. Heard. 2003. *Pestic. Outlook* 14: 145.

Pests and natural enemies of Jatropha curcas: a, Scutellera nobilis inserting stylet into flowers; b, Fruits; c, Bunch. d, Pempelia morosalis webbing inflorescence. e, Larvae; f,Adult; g, Capsule damage. h, Parasite of Pempelia. i, Spider, Stegodyphus sp. j, Bugs ensnared in web. k, Stomphastis thraustica. l, O. versicolor; m, Archaea janata.

The bug *Scutellera nobilis* causes flower fall (see photo 1-a), fruit abortion (1-b), and malformation of seeds. In Jhansi, a main Jatropha production area, this pest was observed to occur at an average of five per bunch, with a maximum of 15 bugs per bunch (1-c). The inflorescence and capsule-borer, *Pempelia morosalis*, also causes economic damage by webbing and feeding on inflorescences (1 d–f) and in later stages boring into the capsules (1-g). However, in Jhansi, it has been observed to be parasitized by the dipteran (1-h) to an extent of 85 percent. Another natural control agent was the spider, *Stegodyphus sp*. (Eresidae: Arachnida), which snared these bugs in its web (1-i).

Elsewhere, the capsule-borer and the bark-eating caterpillar have been recorded as key pests; spraying endosulfan is recommended to control the caterpillar. Other pests that have caused noticeable damage are *Stomphastis (*Acrocercops*) thraustica Meyerick*, the blister miner (1-k), the semilooper *Achaea janata* (1-m), and to a small extent the flower beetle *Oxycetonia versicolor* (1-l).

Monitoring and timely control measures using biological control measures (such as parasites) can also help reduce pest impact. Scelionids like *Pseudotelenomus pachycoris* were found to be effective egg parasitoids of the *scutellarid P. klugii* in Nicaragua. In India, the dipteran parasitoid of Pempelia also offers promise. The entomopathogenous fungi, *Beauveria bassiana* (Bals.) *Vuill*. and *Metarhizium anisopliae* (Metsch.) *Sorok*. (Deuteromycotina: Hyphomycetes) were found to cause 64 to 99 percent mortality of the bugs. *Leptoglossus zonatus* (Dallas) and *Pachycoris klugii Burmeister* can also be used against the *scutellarid* bug in India.

2.6 Harvesting and yields

Jatropha plantations yield between 0.5 and 12 tons of seed/ha or between 200g and 2 kg per plant (Francis et al. 2005). This is a very wide range and demonstrates the need for site-specific yield studies to reduce the uncertainty for a successful business model.

On marginal land in India that is not suitable for food production, yields of 1,200 kg/ha have been achieved after three years and 1,800 kg/ha after 5 years when the plant is in full production (Francis et al. 2005). The productivity of old trees is reportedly declining. However, since most of the *Jatropha* plantations in India are rather young, the optimal age to re-plant improved plants is unknown.

Local researchers in Yunnan and the Yunnan Forestry Department in China are hoping to receive yields of 3 to 4.5 t/ha based on individual wild tree measurements (pers. communication, Ms. Xiao Hua). At high rainfall sites with good soil at lower altitudes (such as Xishuangbanna), yield production is about 7.5 t/ha . At dryer sites with poor soil conditions and at high altitudes, yields of 1.5 t/ha can be achieved (pers. communication, Prof. Xu Ji-hong).

Using drip irrigation systems and fertilizer can highly improve yields. However, there are no reports available from China or India that large-scale plantations are using drip irrigation systems. This may indicate that such an investment is not profitable at current market prices. However, the use of mineral or organic fertilizer is highly recommended. *Jatropha* press cake is a highly suitable organic fertilizer (see section below) and the response is mentioned to be better compared to mineral fertilizer (Francis et al. 2005).

In Table 2, Jatropha yields from wild individual trees are presented from a study conducted by Yunnan Academy of Agricultural Sciences, China. Four study sites representing different site conditions were selected. At each site, tree characteristics and the seeds were collected and analyzed from 110 trees with an age of 13 years in November 2006. All seeds (ripe and unripe) were picked, peeled, and dried before the weight was determined. The average yield was considered on the basis of 1,650 trees/ha. Site No. 1 (barren slope land), due to a lack of sufficient groundwater access and fertilizer, yielded less harvest than the other three study sites. Site No. 2 had good water access and trees received fertilizer. As a result, trees were taller, stronger, with more branches and produced more fruits.

Table 2. *Jatropha* yields from wild individual trees

Site no.	**yield**		**site characterization/management**
	t/ha		
1	1.68		Barren slope land, no management
2	4.53		Village, close to farming land, no management
3	2.15		Barren slope land, no management
4	3.98		Village, close to farming land, no management

Tab. Jatropha yield based on individual wild tree seed measurements in Yunnan (Yunnan, Source: Academy of Agricultural Sciences, 2006)

Depending on the site conditions, *Jatropha* plants can produce flowers and fruits all year around, such as in Xishuangbanna (600 masl). However, in dryer and high altitude sites like Nanling in Guangxi Province, they start flowering in April with a peak in May. In that location, the fruits mature in 3 to 4 months. The main harvesting season is in July-August.[4]

In Nicaragua, well-trained **Jatropha** seed pickers can harvest 30 kg/h (Heller 1996). Of course the harvesting rate is highly influenced by the tree density.

2.7 Seed oil press cake utilisation

A by-product from *Jatropha* oil extraction is a nutrient-rich seed cake containing a large amount of high quality proteins (Makkar et al. 1998). Extracted *Jatropha* kernel seed cake contains about 61 percent crude protein compared to about 45 percent in soybean. Although the roasted seeds of certain *Jatropha* varieties can be eaten, the presence of various toxins (phorbol esters, trypsin inhibitors, lectins, phytates) render the raw seed cake from several other varieties unsuitable for human consumption or as animal feed. Phorbol esters are the most potent among these toxins. The seed content of phorbol esters varies among different *Jatropha* cultivars, ranging from undetectable in the Mexican nontoxic varieties (of which the roasted seeds are eaten by humans) to over 6 mg per g kernel recorded in a toxic variety from India.

However, the raw seed cake is valuable as organic manure (it has more nutrients than both chicken and cattle manure) and would simultaneously serve as a biopesticide/insecticide due to the presence of potent but biodegradable toxins such as phorbol esters. Phorbol esters of *Jatropha curcas* decompose completely within six days (Rug and Ruppel 2000). The leftover

[4] http://www.myqy.com.cn/offer/view.aspx?goodid=6744173

shell also constitutes high energy raw material (19 MJ/kg), which could be used separately. It contains 5.7 to 6.5 percent N, 2.6 to 3.0 percent P2O5, 0.9 to 1.0 percent K2O, 0.6 to 0.7 percent CaO, and 1.3 to 1.4 percent MgO (Francis et al. 2005).

2.8 Contract farming

Detailed information on *Jatropha* contract farming arrangements has not yet been gathered. Expert interviews conducted in Kunming/China do not reveal specific information and there are no publications on this topic. An interesting scheme can be found in the Yunnan Province of China. The provincial government develops *Jatropha* plantations in a partnership arrangement between government agencies, companies, and farmer associations. As a first step, the Yunnan Forestry Department received support from the Yunnan Province government to train forest officers on the ground to mobilize farmers.

2.9 Subsidies

Subsidy-based policies typically involve reductions in motor fuel excise taxes. Blended or undiluted biofuels are taxed at lower rates than their petroleum counterparts, and the tax reduction allows biofuels to be sold to consumers at the same or lower prices. Subsidy-based policies have been very effective at increasing the use of biodiesel in China.

The Chinese Ministry of Finance (MoF) in June 2006 adopted Regulations of Special Financing for Renewable Resources Energy Industry Development. In this regulation, a government subsidy for biopower of 0.25 RMB/kWh is provided. Biomass plants with an output of more than a 20 percent blend of fossil fuel will not be eligible for the 0.25 RMB per kWh subsidy. The subsidy will cease when the project has been operating for 15 years (Credit Suisse 2006).

Furthermore, the Chinese Government promised to provide a 50 percent tax break for investments in renewable **energy** and to use the tax from carbon credits to support renewable energy production.

Direct financing support and tax breaks for the biodiesel processing industry are expected, but implementation procedures are still unclear. Currently, the central government is supporting *Jatropha* production by initiating and supporting research. In addition, the Yunnan provincial government is investing in *Jatropha* plantations and a processing industry. The Yunnan Forestry Department seems to be the main beneficiary from this program and is using these funds to provide a reward to the district forest officers for each ha of *Jatropha* plantation established in every district.

2.10 Carbon credits from biodiesel production and consumption

Along the Jatropha biodiesel production supply chain, a project can theoretically claim emission reductions three times:

1) Afforestation/reforestation-related temporary emission reductions (Annex I country CDM project activity);

2) Renewable energy certified emission reductions (for example, biodiesel is consumed in an Annex II country and replaces the use of fossil fuels); and
3) An Annex I country can claim the emission reductions from replacing fossil fuels with biofuels in the National Allocation Plan.

However, the UNFCCC EB 26 decided that this kind of double counting (defined as emission reduction credits being claimed by more than one claimant in the production supply chain) is not permitted. It was further decided that biofuel producers can claim CERs only if the biofuel consumption is considered in the project boundary and monitored. CERs cannot also be claimed for biofuels that are exported to Annex I countries. The UNFCCC Methodology Panel is currently developing a tool for the avoidance of double counting in biofuel CDM project activities (pers. communication, Neeta Hooda, UNFCCC Secretariat).

Biodiesel production-related CDM methodologies

Currently there is no CDM methodology for biodiesel production, but the existing methodology AR-AM0001—Reforestation of degraded land—developed in China can be modified. The major challenge for a biodiesel production-related CDM methodology will be to consider the production-related emissions; that is, fertilizer use, transport, production process, and project leakage. A life cycle assessment to develop the project baseline can be quite demanding. An existing methodology from the United States for soybeans can be modified (USDOE 1998). The project developer can also decide to establish a portfolio of small-scale AR CDM projects.

The first portfolio of small-scale AR CDM projects from Uganda was recently presented to UNFCCC. If the projects are approved, this simplified methodology could be used as long as individual projects produce not more than 8,000 tCO_2/year and if project boundaries are at least 1 km apart from each other. However, the question remains whether the relatively low *Jatropha* biomass sequestration rate per ha, combined with the market value of tCERs, can justify the investment and monitoring costs. Large-scale *Jatropha* projects can also claim tCERs temporarily until biodiesel is produced and CERs from renewable energy are claimed.

Biodiesel consumption-related CDM methodologies

For biodiesel consumption, the first CDM methodology was approved in February 2007 for the Biolux project in China. The AM0047—Production of waste cooking oil-based biodiesel for use as "fuel" methodology—can be also applied for *Jatropha*-based biodiesel consumption.

In South Africa, a Japanese carbon fund conducted a feasibility study to assess GHG emission reductions for a 100,000 t/year *Jatropha*-based biodiesel project. According to this study, the project will produce 260,000 tCo_2 per year from the replacement of fossil fuels (Table 3).

Table 3. GHG mitigation of a *Jatropha*-based biodiesel project	
PARAMETER	**GHG EMISSIONS / REDUCTIONS** in t/year Co_2
GHG emissions due to the project	98,000
Leakage	12,000
Total GHG emissions due to the project	**110,000**
Baseline emission	370,000
GHG emission reductions	**260,000**

Tab. GHG mitigation of a Jatropha-based biodiesel project with an output of 100,000 l (Mitui & Co Ltd for Ministry of S. Africa, 2005)

2.11 *Jatropha* economics

When producing diesel from *Jatropha*, the feedstock production costs alone represent between 60 and 80 percent of total production costs (Credit Suisse 2007). The processing costs contribute 12 percent and the distribution costs 6 percent to the total costs, according to Credit Suisse (2007). This demonstrates that reducing the feedstock production cost has the greatest potential to reduce the overall production costs of biodiesel.

A detailed economic study from the Daimler-Chrysler *Jatropha* plantations on marginal land in India revealed that if farmers receive 0.85 RMB/kg of *Jatropha* seeds and have an additional income from vegetable intercropping, they can achieve an internal rate of return of 21 percent on their investment. Considering the above feedstock price, the refinery costs to produce biodiesel are 4.1 RMB/l assuming an internal rate of return of 16 percent. If the glycerol and seed cake byproducts can be sold, biodiesel can be offered at 3.1 RMB/l (Francis et al., 2005).

In Germany, biodiesel from rapeseed has production costs of 7.9 RMB/kg. If the byproducts can be sold—that is, press cake for 0.17 RMB/kg and glycerine for 0.07 RMB/kg—the net production costs are 5.9 RMB/kg. The retail price at fuel stations is 8 RMB/l. Glycerol can be used for three purposes: material production (plastics and fibers), thermal biomass combustion, and possibly as an alternative energy source.

Currently, the market for *Jatropha* seed is highly volatile. According to KIB, seeds were traded during the first six months of 2006 for 0.8 to 1 RMB/kg.; Prof. Xu Jihong of Yunnan University confirms this price. The Yunnan Forestry Department quoted that small quantities were traded for 7–8 RMB/kg in February 2007. This is an indication that the market is not well-developed and that there is currently a huge demand for seeds to establish plantations. High prices for improved seeds and site-specific varieties can be justified, but currently there seems to be hardly any improved seed available. The quality of seed offered in the market is often just ordinary seed from wild *Jatropha* plants with a fake label or origin and no provenance information.

Studies comparing income opportunities from *Jatropha* with other cash crops are rare. According to a study of the Green Poverty Reduction Programme, a household can generate an annual income (profit) of 250–400 RMB/mu from *Jatropha* after 3–5 years. This seems very low, and suggests that more in-depth household income studies from Jatropha are needed.

Studies are needed to assess the opportunity costs for farmers to switch to *Jatropha* production. To get a better idea of opportunity costs, we need information on production system inputs and outputs ($/ha) and a comparison with other agricultural crops on marginal agricultural land. The study design must also consider different altitudinal zones (for example, maize and grain growing zones) and respective incomes per ha.

Box 3. More facts about *Jatropha* cultivation
• *Jatropha* grows well on low-fertility soils (prefers alkaline site conditions, though); however, increased yields can be obtained using a fertilizer containing small amounts of magnesium, sulfur, and calcium.
• *Jatropha* can be intercropped with many cash crops—such as coffee, sugar, fruits, and vegetables—with the *Jatropha* offering both fertilizer and protection against livestock.
• *Jatropha* needs at least 600mm of rain annually to thrive; however, it can survive three years of drought by dropping its leaves.
• *Jatropha* is excellent at preventing soil erosion. The leaves it drops act as a wonderful soil enriching mulch.
• The cost of 1,000 *Jatropha* saplings (enough for one acre) in Pakistan is around £50, or just 5p each. In India, the cost of 1kg of *Jatropha* seeds is 6 rupees (equivalent to approximately £0.07).
• *Jatropha* seedlings should be planted at 2x2m, 2,200-2,500 trees/ha, or 1,000/acre.
• The mortality rate for seedlings is around 20 percent.
• One job is created for each 4 hectares of *Jatropha* plantation.

… and about the yield and returns of Jatropha cultivation
• One hectare should yield around 7 tons of seed per year.
• *Jatropha* seedlings yield seeds in the first year after plantation; within five years, the typical annual reaches 3.5kg of beans.
• *Jatropha* trees are productive for up to 30 to 40 years.
• The yield of a *Jatropha* plantation in India is 25,000 Rs/year/ha (around £300).

3 INTERNATIONAL EXPERIENCE WITH JATROPHA AS A BIO-DIESEL

3.1 Global biofuel markets

The new global interest in biofuels has already translated into rapidly expanding international biofuel markets. A growing number of industrialized and developing countries have introduced policies to increase the proportion of biofuels in their energy portfolio.

With the Kyoto Protocol's recent entry into force and the worldwide implementation of national targets for biofuels, it is expected that in the next 20 years global biofuel production will quadruple, accounting for about 10 percent of world motor fuel (IEA 2004).

Whereas at least 90 percent of biofuel production is consumed domestically, international trade in biofuels is expanding rapidly.

Countries such as Japan, South Korea, and the United States, and some in Europe, will not have the domestic capacity to meet national demand and are therefore looking to other countries to fill the gap and meet their ambitious targets. For instance, the EU's goal of 5.75 percent biofuels in the fuel transport blend by 20101 would require a fivefold increase in regional production.

Indonesia and Malaysia are already expanding oil-palm plantations to meet this growing demand. Together they are expected to supply up to 20 percent of the EU market. In the Netherlands, it is expected that 80 percent of the necessary feedstock will be imported due to the small arable crop area available and the ambitious biofuels goal set by the government (Gains Report 2006). Brazil is also expected to be an important beneficiary of EU demand for soy for biofuel. Other palm oil producers such as Ecuador and Colombia and traditional soy and coconut oil exporters such as Argentina and the Philippines are also seizing bio-diesel trade opportunities. Several African and Asian countries are exploring the benefits of large-scale production and trade of fast growing, drought-resistant feedstock (for example, *Jatropha* tree seeds).

Bioethanol is by far the most widely used biofuel for transport, accounting for more than 94 percent of global biofuel production.

About 60 percent of bioethanol comes from sugar cane and 40 percent from other crops (Trindade 2005). Brazil is the largest bioethanol exporter, supplying about half of the global market.

Other traditional sugar exporters—including Guatemala, El Salvador, Pakistan, South Africa, and Swaziland—are also looking at opportunities derived from bio-ethanol production and trade.

Box 4. Biofuels: some basic notions

Biofuels are products that can be processed into liquid fuels for either transport or heating purposes.

Bioethanol and biodiesel are two of the most common forms of biofuels. Others include biomethanol, biodimethylether, and biogas:

- Bioethanol is produced from crops such as sugar cane, corn, beet, wheat, and sorghum. A new generation of 'lignocellulosic' bioethanol also includes a range of forestry products such as short rotation coppices and energy grasses.
- Biodiesel is made from seeds such as rapeseed, sunflower, soy, palm, coconut, or Jatropha. New biodiesel technologies—such as the Fischer-Tropsch process—can synthesize diesel fuels from wood and straw to a gasification stage.

Raw materials used to produce biofuels are referred to as feedstock.

3.2 Bio-diesel processing

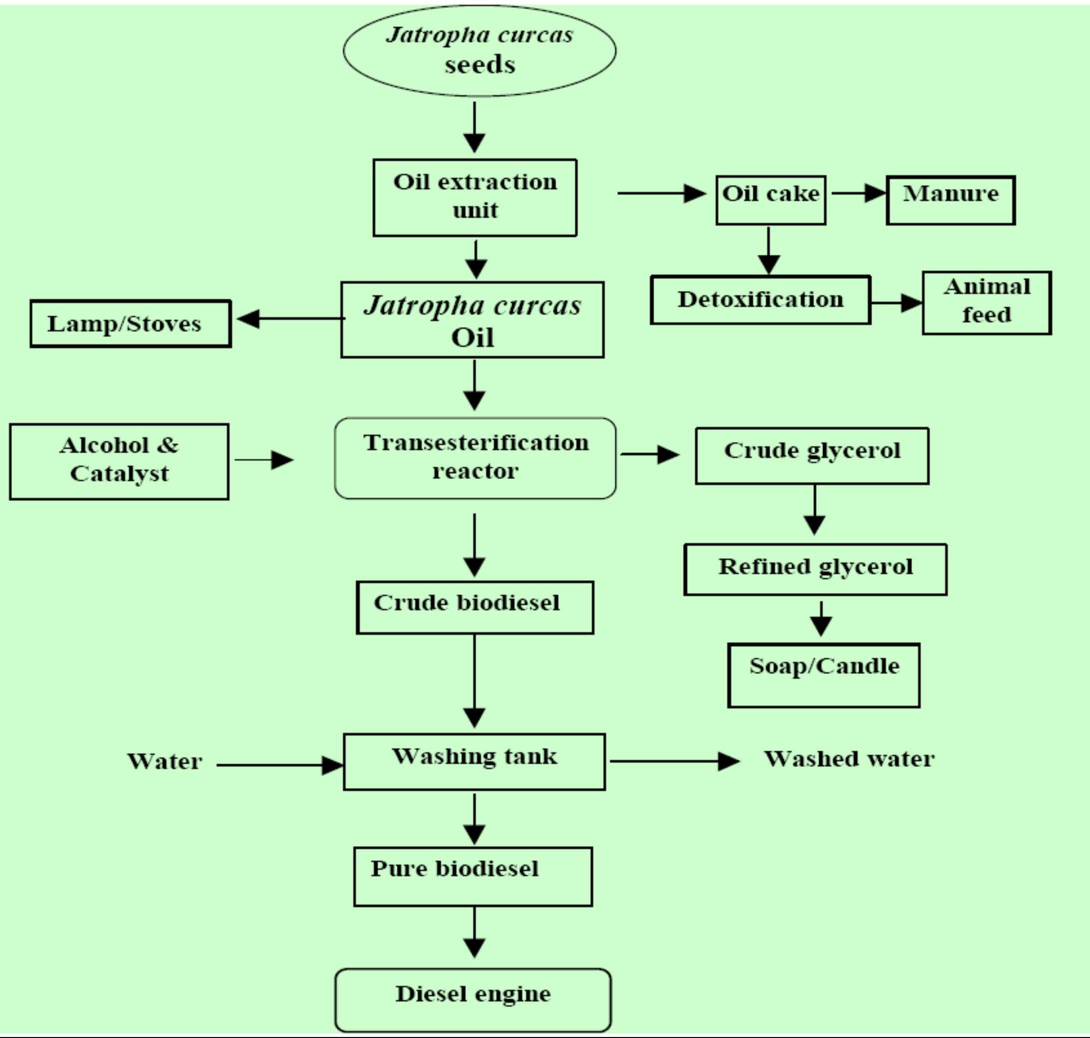
3.2.1 Introduction

This chapter summarizes the steady state of *Jatropha* seed crushing and biofuel refinery technology and capacity. The general biofuel refinery process is presented in the flow chart (Figure 1).

The process involves the following steps: (a) crushing and pressing of *Jatropha curcas* seeds; (b) oil extraction and separation; (c) recovery of solvent; and (d) removal of phosphatide, alkali treatment, discoloration, transesterification conversion, glycerol concentration, and glycerol refining.

The refinery process roughly requires 3.5 to 4 kg of *Jatropha* seeds to produce 1 kg (or 0.84 l) of *Jatropha* oil and 0.1 kg of glycerol (Francis et al. 2005; pers. communication, Prof. Xu Jihong).

Figure 1. **Jatropha biofuel refinery process and by products**



Jatropha biofuel refinery process and by products along the processing chain.

3.2.2 Crushing and oil filtering

Depending on the technology, 60 to 80 percent of the oil content can be extracted during the crushing process. It is important to remove soil, stones, and plant parts before the oil is pressed to reduce the risk of damaging the press and to receive a cleaner oil that results in a higher refinery efficiency. A sieve is usually installed to remove stones and plant parts and a magnetic separator removes possible metal parts. After the press, a homogenizer prevents oil parts from separating based on their density. An automatic compressed air filter is used to clean the oil before the oil is stored in a metal tank under cold conditions (Fercher 2000).

Currently, with the limited amount of available *Jatropha* seeds, seeds are crushed with the same technology as other oil crops. This is not very efficient in terms of technology. Considering that *Jatropha* seeds are highly toxic, there is also a risk that cooking oil is contaminated with *Jatropha* oil. Therefore, *Jatropha* crushing technology should be introduced that can not be easily switched for edible oil seed crushing.

3.2.3 The biodiesel refinery process—existing and planned production capacity

Simple diesel engines can operate on pure filtered Jatropha oil, but the high viscosity is a problem for the ignition of the engine. To solve the problem, adaptation kits with dual fuel tanks to start the engine with diesel and to switch to *Jatropha* oil when the oil is warm are available from Elsbett in Germany (Janske van Eijck 2006). Prof. Xu Jihong mentioned that he is blending 30 percent filtered *Jatropha* oil and an additive with diesel to operate his car.

After the oil is refined into biodiesel, it can be blended with diesel and used in the fuel station supply chain and in modern engines.

Biodiesel is a mixture of long-chain fatty acid esters, conventionally manufactured through trans-esterification of triacylglycerol. Any oil-based/fatty organic matter can be used for biodiesel production. *Jatropha* oil, rape seed, soybeans, palm oil, and animal waste are typical feedstocks used for biodiesel production. The U.S. continues to rely on soybeans. EU countries have relied principally on rapeseed for biodiesel production for the first generation of biodiesel, and many Asian countries are looking to process palm oil into biodiesel.

Biodiesel production is technologically more complex than ethanol production, but it is still fairly simple. Large amounts of glycerol result as by-products of biodiesel production (1 kg of Glycerine per 10 kg of biodiesel). Its economic use is important for competitive biodiesel production.

3.2.4 Direct fuel for engines

Straight vegetable oil (or pure plant oil, PPO) is a very suitable fuel for diesel engines. Unfortunately, most contemporary diesel engines have evolved so far to the use of fossil diesel fuel that more or less decisive adaptations will be necessary to run these engines successfully with PPO for a longer period. On the other hand, most diesel engines that are in use in developing countries still rely on older technology. Hence the use of PPO with little or no modification is often possible.

The most important distinction is between direct injected engines and pre-chamber engines. The first category is generally more sensitive to its fuel and operating conditions and should not be run with vegetable oil or blends without adaptations.

The second category of indirect injected engines is less sensitive. In these engines, the fuel is not atomized into the combustion chamber itself, but into a small prechamber. Here combustion starts and the burning gases rush through the connecting channel into the actual combustion chamber above the piston. As the combustion starts in a concentrated way in the very hot prechamber, the fuel's nature and quality are not so important. Depending on the environment (temperature), the type of PPO (rapeseed, *Jatropha*, or thicker oils like palm or castor) and the usage of the engine, it may be possible to switch to PPO without conversion of the engine. The warmer the environment, the thinner the oil, and the more continuous the usage of the engine, the more feasible it is to use PPO. A good strategy to discover the possibilities of your set-up is to gradually increase the amount of PPO in the mix with diesel. Of course, a good overall condition of the engine (compression, injector wear) is required, as PPO generally has higher requirements than diesel. You could start with about 25 percent

PPO, 75 percent diesel, and if successful, increase the PPO fraction in the next tank filling. If the engine begins to give starting difficulties or the full power is no longer developed, then you have reached the maximum percentage of PPO for the current configuration. The last increments of diesel make the largest difference.

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

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

The first problem is mainly an issue in temperate climates or with very viscous oil, like palm oil or castor (*mamona*) 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 can deliver a lot of heat, and second because the coolant water has the ideal temperature of close to 100° C. Heating the PPO with heat from the exhaust may seem attractive (it can be the only option in air-cooled engines) but has the large danger of temperatures going too high, causing the PPO to crack chemically (above 150 °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 issues, it is important that the injectors are in proper condition. These parts ensure the fuel is atomized (sprayed into very fine droplets) for combustion. In case of prechamber car engines in Europe, the guideline is that the opening pressure of the injector (reflecting its condition) should be checked after 100,000 km. If no special PPO injectors (like those offered by Elsbett) are installed, it is advised to increase the opening pressure of the new injectors by 10–20 **bars** and to advance the injection timing of the engine a bit. Engine specialists are able to adjust the engine timing auditively; that is, the converted engine should give the same combustion sound on PPO as it did with diesel. 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.

For a proper cold start with PPO, the preglowing system (if available) should be in good working order. It is advisory to double the preglowing time (manually or by adjustment). Eventually, longer or more robust glow plugs can be installed. To minimize cold start emissions, some afterglowing is useful.

This also holds for direct injected (DI) engines. But as the fuel injection is done immediately on top of the piston, into the relatively cold combustion chamber, the DI engine has more prerequisites toward conversion.

Even more than prechamber engines, DI engines come with a variety of pump concepts. The line pump and distributor (rotary) pump are least problematic in conversion, as they are often quite tough. Attention should be paid if your engine has a distributor pump manufactured by Lucas/CAV, Delphi, Stanadyne, or Roto-Diesel.

Because of their construction, these pumps are less-suited for PPO. Usually, distributor pumps by Bosch, Diesel-Kiki, Nippon-Denso, or Zexel are more robust. Line pumps are always of strong construction and can handle cold PPO. In unconverted DI engines of these types, it is not recommended to try blends of more than 30 percent PPO. More modern types of DI engines (made in the last ten years) may be equipped with common rail injection or unit injector systems. These systems contain rather sensitive (and precious) high tech and are always computer controlled. These are reasons not to try experiments with PPO in these engines.

It is common practice to convert DI engines with a two-tank system. A small tank is added to contain diesel for cold starting and the warm engine can be switched to PPO from the main tank. In this way, the cold start phase with PPO, which is the most critical phase, is avoided. For the rest, the conversion resembles that of a pre-chamber engine.

Even after conversion, it is good to remain careful with the engine until learning how it behaves with PPO. Like with the pre-chamber engine, it is advisable to increase the PPO percentage in steps and only to increase to a higher PPO content if the engine completed the previous step successfully. That means it has to run like it did before and start like it did before conversion. If the engine emits smoke more than occasionally, it's good to search for a reason. Gray smoke at full load means too much fuel, too little air, or contamination in the combustion chamber. Blue smoke means oil consumption, which may be caused by coking of the oil springs around the piston. At idle, gray smoke is an indication of incomplete combustion because of worn injectors or too little compression.

It is very important to keep an eye on the engine oil. The consumed volume of oil has to be added. The replacement intervals of the engine oil should be shortened (to half or two-thirds of the original length) because the oil is much more stressed with PPO as a fuel, especially if the engine is used for short runs or with very high load. It is especially important to watch for a rising oil level, which indicates that the lubrication oil is diluted with PPO. If this happens, the oil should be changed fast and the cause of the dilution has to be solved. This cause can be, for example, a lot of cold operation of the engine, a lot of low-load operation (especially running idle), or a bad injector. As this suggests, DI engines do not run at idle for prolonged periods. It is better to switch the engine off and on again.

3.2.5 Feedstock for biodiesel production

Instead of adapting the engine to run on PPO, the oil can also be chemically treated to produce biodiesel. Properties of biodiesel are very similar to those of fossil diesel, and hence it can be used in any diesel engine without adaptations. Disadvantages to the user are its slightly lower energy content, leading to an increase in fuel consumption of about 2–10 percent, 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. As a result, 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.

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, glycerin is formed.

Methanol is usually used as an alcohol, made either from natural gas or

crude oil. Theoretically, ethanol could be used as well, with the advantage that it can be easily produced in a biological way, for example by fermentation. The use of ethanol has three disadvantages:

- Ethanol is more expensive than methanol, but homemade ethanol is cheaper.
- The esterification process with methanol is a lot more straightforward and easy than with ethanol. One of the problems is that the ethanol must be free of water (anhydrous), which is not easily accomplished in a nonindustrial setting. Distillation alone is not enough, as it only yields 95 percent pure ethanol at most.
- The properties of methyl esters are more favorable than those of ethyl esters. In particular, the cold-related properties like CFPP and viscosity lag behind. Although these are not of such importance in tropical climates, the author would personally choose to convert the engine to SVO instead of going through the hassle of producing ethyl ester when its gain in properties is so marginal.

For these reasons, the remainder of this discussion assumes the use of methanol.

3.2.6 Biodiesel production recipe

Generally, this recipe can be followed to produce biodiesel from fresh PPO and methanol in a base-catalysed environment. The recipe below is a very much summarized general guideline. Many tips and tricks and safety recommendations have been left out for the sake of compactness. It is good to read more about this before starting. If you would like to use used cooking oil, ethanol, or another catalyst instead, many Internet sites can help you adapt the recipe. Please note that the methanol and lye involved are quite dangerous chemicals. Be sure to know what you are doing, work in a well-ventilated area, and wear protective clothes and glasses!

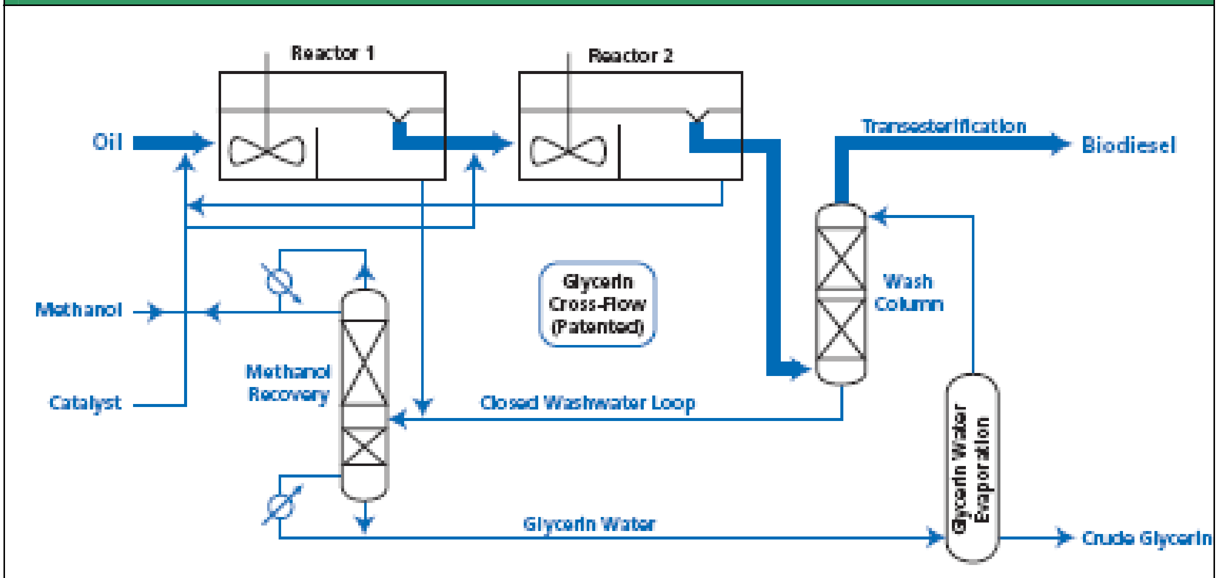
The following resources are required (all quantities are expressed per liter of PPO): 1 liter of PPO, the younger the better; 5 grams of lye (caustic soda; NaOH (> 95 percent) or KOH (> 85 percent); and at least 220 ml of methanol (> 99 percent).

First, dissolve the lye into the methanol. Shake or swirl until all the lye has dissolved. This may take 10 minutes. It is normal that temperature rises. This mixture is called sodium methoxide. Now make sure the PPO is in a vessel large enough (at least 150 percent of its volume), preferably with a valve at the bottom, and heat it to about 60 °C, then stop heating. Then add the methoxide mixture and make sure it is mixed well for at least 10 minutes. Leave the vessel and let the different constituents separate by sedimentation. The glycerine will settle out at the bottom. After 8 to 24 hours, the sedimentation is complete and the glycerine can be drained off. What remains is raw biodiesel. If the reaction went well and the biodiesel is clear, it may be used straight, although its quality may be inferior because of impurities. Water washing will remove most of these impurities. Consult any of the websites listed below to gather more information about this.

3.2.7 Technology provider

The market leader in biodiesel processing plants is Lurgi in Germany. They have build 38 turnkey biodiesel plants worldwide with a capacity between 40,000 and 250,000 tonnes. It is estimated that 60 to 70 percent of the worldwide biodiesel production capacity is installed by Lurgi (Figure 2).

Figure 2. The Lurgi transesterification process



Another German company SKET Cimbria, represented by Beijing FaitH Oil New Technology Corporation, is a leading provider of oil pressing and refinery technology.

Chinese companies only have experience with small plants with a production capacity up to 40,000 t/year. In this range, turnkey plants cost 8 million RMB and are 30 to 40 percent cheaper than imported technology.

3.3 A look at the financial costs of commercial *Jatropha* cultivation for Biodiesel

Jatropha is perceived by many to be the perfect biodiesel crop. It can be grown in very poor soils (actually generating top soil as it goes), is drought and pest resilient, and it has seeds with up to 40 percent oil content.

In China, the Yunnan Provincial Government Research Institute has published a study on production costs of ethanol from cassava, sweet potato, and sugar cane and on biodiesel (feedstock crop not mentioned in the report, but most likely *Jatropha*) (Table 4). According to this study, ethanol production is more cost effective, in particular straw-based ethanol production. However, biodiesel production has the most favorable feedstock input to biodiesel output ratio.

Currently, biofuels (ethanol and biodiesel) are traded for 5,268 RMB/ton. No. 90 gasoline has a retail price of 5,783 RMB/ton, which includes taxes of 610 RMB/ton and a processing fee of 640 RMB/ton.

Table 4. Production costs of biodiesel and ethanol in China

CROP	TOTAL TARGET PLANTATION AREA (million mu)	RAW-MATERIAL COSTS (in RMB/t biomass)	INPUT/OUTPUT RATIO (Raw material/ biofuel)	RAW MATERIAL COSTS (in RMB/ per t raw-material)	BIOFUEL PRODUCTION COSTS (in RMB/t)
Cassava/ Tapioca	8	350	7.0 : 1	2,450	3,700
Sweet potato	5	350	8.5 : 1	2,975	4,225
Sugarcane	4	300	12.0 : 1	3,600	4,850
Straw		200	6.0 : 1	1,200	2,450
Biodiesel	15	300	5.0 : 1	3,600	4,250

Tab. Production costs of biodiesel and ethanol (Source: Yunnan Provincial Government Research Institute).

The feedstock production costs for rapeseed are 6,480 RMB/ton, according to a study from Credit Suisse (2007). Recycled cooking oil has the lowest feedstock costs of 1,650 RMB/t biodiesel.

However, the study doesn't take into account that only *Jatropha*-based biodiesel production can utilize land that is not suitable for agricultural production; that is, *Jatropha*-based biodiesel production is not competing with food production.

3.4 More facts about *Jatropha* biodiesel production

- The oil pressed from 4kg of seeds is needed to make 1 liter of biodiesel.
- Ninety-one percent+ of the oil can be extracted with cold pressing.
- One hectare yields around 2.2 to 2.7 tons of oil.
- Press cake (seedcake) is left after the oil is pressed from the seeds. It can be composted and used as a high-grade nitrogen-rich organic fertilizer (green manure). The remaining oil can be used to make skin friendly soap.
- Biodiesel costs around 16 to 20p per liter to grow and refine in India.

- Glycerol, a byproduct of biodiesel refinement, can be sold in India for around 45–70p/kg.
- One t of seedcake (the leftovers after pressing) fetches around $100 (£55).
- The landed cost of 1 ton of *Jatropha* oil to Northern Europe is between $348 and $500 for oil content of 29 percent to 40 percent (£180 to £260). Refining *Jatropha* oil into biodiesel costs less than $125 (£65)/t.
- Filtered *Jatropha* oil can be used as is in many diesel vehicles (as SVO) with only small modifications required to the engine.
- *Jatropha* oil can be used as a kerosene substitute for heating and lamps.

4 BUSINESS MODEL CONCEPT OUTLINE FOR KENYA

4.1 Concept outline

The two PINs could be combined and timed so they follow one another in time: the land use (sequestration) module in a first commitment period 2008–12, followed by a fuel switching component that becomes viable once the plants are producing a sufficient amount of feed-stock (after 2013 or earlier).

The following institutional set-up could be be considered:

- **KenGen**. KenGen is the main potential "buyer" of *Jatropha* feedstock and catalyzer for the technological adaptations required for power generation.
- **Kenya Forest Service**: KFS acts as "aggregator," securing the extension and providing technical assistance for *Jatropha* cultivation (seconded by KEFRI as the "researcher").
- **KTDA**: KTDA is an "additional producer + buyer." The agency will secure an important share of the feedstock production through its associated farmers; at the same time, KTDA's factories could buy the majority of the feedstock produced by their farmers.

4.2 Respective role of the key stakeholders

The **Kenya Forest Service (KFS)** could play the role of an "aggregator" of the AFOLU PIN. It is in a position to secure the required extension services to produce the very substantial amount of plants required and to distribute them among farmers. The "Farmer Field Schools" offer a good institutional platform for such extension work.

KFS's close association with KEFRI will ensure that results of ongoing research on *Jatropha* in Kenya will be reflected in field activities. KFS has access to KShs 8m that could be used as seed money (+ additional KSh 8m that might be added by the Belgian government) to set up a revolving fund for forest conservation and forest-based social development (forest-based micro-enterprises, acquisition of technologies, development of ecotourism, processing of NTFPs). Implementation of pilot activities under this fund will be started as soon as possible (within this fiscal year) so that the assistance does not lapse. The pilot activities are meant to be followed by scaling up with a KShs 140m topping up to the fund by the Japanese government. The rehabilitation of degraded land and the promotion of *Jatropha*-based microenterprises would be fully in line with the intended focus of the fund

KenGen can secure the market for *Jatropha* feedstock by issuing a purchase guarantee for 12–15 years. The company has already presented nine PINs to the WB Carbon Finance Unit. To date, six have been accepted; all are related to hydropower and geothermal power, none to biofuels. KenGen is going to be a key player in the "Kenya Environmental and Social Responsibility Project" (KShs 500m, other partners: MoEnergy, Kenya Oil Corporation) One of the planned activities is a 50ha-*Jatropha* plantation with 100,000 seedlings. KenGen's mission statement includes the pledge to undertake an environmentally friendly expansion of its current capacities.

KTDA and its tea factories are another potential major buyer of biodiesel. So far, KTDA factories rely mainly on furnace oil, fuelwood, and electricity (from the national grid or from the factories' own generators). In addition to electricity required for lighting and driving motors and withering fans, an average tea factory needs 12,000 m^3 of wood (equivalent to 50 ha of eucalypthus plantation harvested in a five-year rotation). Alternatively, it requires 1.6m liters of furnace oil valued at KShs 50m/year.

KTDA has huge assets and a comparative advantage. The agency represents 92,000 ha of tea plantations (yielding 60 percent of the Kenyan tea production). Farmers own the 57 processing units/factories of KTDA on a shareholder basis. KTDA is therefore strongly rooted among Kenya's tea farmers. It does not want to further extend the land under tea. Its nurseries (each of the factories has one) are now being converted "from tea nurseries to tree nurseries" in order to meet the growing demand for Eucalyptus saplings (for fuelwood production)

NGOs: So far, no NGO has been identified that would be in a position to scale up current trials with *Jatropha* to a large national scale. Perhaps a combination of NGOs could perform this function.

GreenAfrica is driven by a strong environmentalist vision. Tree saplings are generally given to farmers free of cost. This includes about 1,000 acres of *Jatropha* plantations plus 300kg of Jatropha seeds. Ninety percent of these plantations are not faring well and are not producing the expected yields. So far, there has been little if any assistance provided to farmers to market their trees or tree products;. GreenAfrica seems to be well-connected to politicians and state institutions (includingKEFRI). It has recently been approached by "Asian Carbon Emission Management" (India) to assist in the formulation of a CDM project for the voluntary market. A research **cooperation** is being developed with a professor at the University of Hiroshima focusing on small-scale, decentralized power generation.

VI Agroforestry (VIA/SCC): This is a Swedish NGO that has joined forces with the Swedish Cooperative Centre (SCC) to implement their Lake Victoria Development Programme. VIA has been active in the region since 1983. The main focus of the work of VIA/SCC includes a) agroforestry extension for smallholder farmers and provision of planting material (trees for timber, fodder, and fruit production and b) marketing support to the farmers to sell their tree products. While VIA is only providing the seeds (and knowledge about how to raise them successfully), it is the farmers themselves who raise, plant, and manage the trees (with the support of the VIA/SCC extension team). In 2006 alone, VIA produced and distributed 30 tons of tree seeds (83 species); the resulting hectare coverage has yet to be calculated. This system is a very strong asset of the organization, together with the extension service comprising almost 700 extension workers.

Catholic Relief Service (CRS): This American NGO works through local partners. CRS focuses on food security, food production, and food-for-work programs. Carbon finances is seen as an element that would provide additional and sustainable revenue to these activities. While CRS so far has no first-hand experience in the cultivation of *Jatropha*, its team of 60 advisors/extensionists and the associated national partners make it a strong candidate to play a leading role in building up an extension service for *Jatropha* cultivation.

Other organizations that have been consulted and should be included in a continuous exchange of experiences include:

- **GTZ** (Regional Energy Advisory platform)
- **DEG (German Development Bank)** has launched a 200,000 EUR PPP project to assist up to 15 medium-scale companies in establishing *Jatropha* plantations to mitigate environmental damages of these industries. DEG's *Jatropha* support program is a public-private partnership (PPP) that is supported with EUR 200,000 by the bank. The 12 to 15 Kenyan companies benefiting from the scheme will have to contribute an additional EUR 200,000 of their own capital resources. DEG has requested not to involve these groups under the current scheme so as not to interfere with the consolidation of their recently launched activities.

4.3 Funding / seed money

Production of the feedstock for the estimated 20,000 to 30,000 ha of *Jatropha* plantations shall be secured through (a) large landowners, including KenGen and large ranchers, and (b) small farmers, who will have to be organized in producer associations to secure a reliable production of the feedstock.

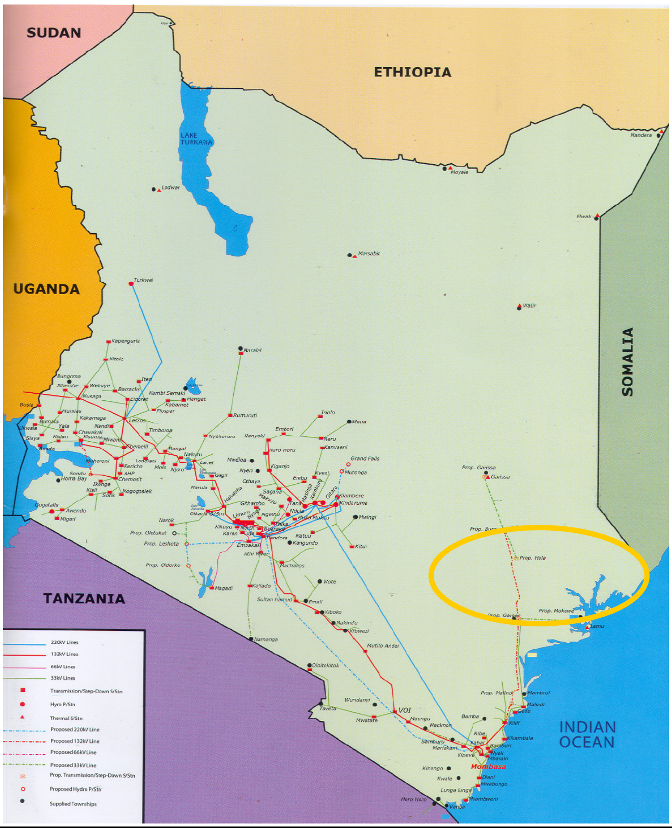
4.4 Selecting a region for the production of *Jatropha* feedstock

4.4.1 Regional integration of *Jatropha* into the Kenya power grid

The majority of thermal power generation is located along the coast, while the lands best suited for *Jatropha* cultivation are further inland; possibly, the feedstock could be produced and processed there. The oil could then be transported down to the coast for energy generation (Figure 3).

Alternatively, KenGen is ready to envisage the installation of additional power producing capacities inland, even without connection to the national grid, to promote a decentralized production of power

Figure 3. The Kenya power grid
(with area of the suggested *Jatropha* outgrower scheme)



Source: KenGen, 2007

4.4.2 Kenya's power system operations profile

Table 5. Kenya's Power System Operation Statistics (2001-2006)

COMPANY	Capacity (MW) as at 30.06.2006							
	Installed	Effective[1]	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
KenGen								
Hydro:			Energy Purchased (GWh)					
Tana	14.4	10.4	71	76	65	65	59	56
Wanjii	7.4	7.4	47	52	51	34	21	22
Kamburu	94.2	88.0	181	330	470	470	381	399
Gitaru	225.0	216.0	364	665	945	938	757	795
Kindaruma	40.0	40.0	81	162	224	221	170	190
Small Stations	6.3	4.9	20	23	25	28	23	20
Masinga	40.0	40.0	28	127	206	230	169	170
Kiambere	144.0	144.0	292	703	999	1010	814	852
Turkwel	106.0	106.0	240	264	136	263	475	520
Hydro Total	**677.3**	**656.7**	**1,325**	**2,402**	**3,120**	**3,259**	**2,869**	**3,025**
Thermal:								
Kipevu Steam	0.0	0.0	126	94	83	56	48	0
Kipevu I Diesel	75.0	60.0	449	268	144	279	330	399
Fiat - Nairobi South	13.5	10.0	35	1	0.2	-0.02	3	18
Kipevu Gas Turbines	60.0	60.0	274	77	20	4	97	194
Garissa & Lamu	5.2	4.6	10	11	12	13	13	15
Thermal Total	**153.7**	**134.6**	**894**	**451**	**260**	**352**	**491**	**626**
Geothermal:								
Olkaria I	45.0	45.0	340	377	277	266	371	324
Olkaria II	70.0	70.0	0	0	0	417	549	562
Geothermal Total	**115.0**	**115.0**	**340**	**377**	**277**	**682**	**920**	**886**
Wind								
Ngong	0.4	0.4	0.1	0.0	0.3	0.4	0.4	0.4
KenGen Total	**946.3**	**906.7**	**2,559**	**3,230**	**3,657**	**4,294**	**4,280**	**4,538**
Government of Kenya (Rural Electrification Programme)								
Isolated Thermal Stations	6.1	5.1	10	10	10	10	11	11
Independent Power Producers (IPP) - Thermal & Geothermal								
Iberafrica	56.0	56.0	348	348	251	240	330	408
Westmont[2]	0.0	0.0	277	149	29	15	3	0
Tsavo	74.0	74.0	7	550	473	200	508	570
Mumias - Cogeneration	2.0	0.0	6	1	0	0	0	9
Or Power 4 - Geothermal	13.0	13.0	89	103	109	105	115	117
IPP Total	**145**	**143**	**727**	**1151**	**862**	**560**	**956**	**1,103**
Emergency Power Producers(EPP)[3]								
Aggreko	80.0	80.0	303	0	0	0	0	30
Cummins			174	0	0	0	0	0
Deutz			111	0	0	0	0	0
EPP Total	**80.0**	**80.0**	**587**	**0**	**0**	**0**	**0**	**30**
Imports								
UETCL	0.0	0.0	198	172	222	171	99	15
TANESCO	0.0	0.0	0	0	0	0	0.3	0.4
Total Imports	**0.0**	**0.0**	**197.8**	**172.0**	**222**	**171**	**99.0**	**15.0**
SYSTEM TOTAL	**1,177**	**1,135**	**4,081**	**4,563**	**4,750**	**5,035**	**5,347**	**5,697**
SUMMARY OF KEY STATISTICS								
SALES - KPLC System (GWh)			3,091	3,498	3,654	3,940	4,200	4,420
- REP System (GWh)			121	130	147	150	164	186
- Export to Uganda (GWh)							15	24
TOTAL SALES (GWh)			**3,212**	**3,628**	**3,801**	**4,090**	**4,379**	**4,630**
System Losses (GWh)[4]			869	936	949	946	968	1,067
System Peak Demand (MW)[5]			724	760	786	830	899	920
System Load Factor			64.4%	69.0%	69.4%	69.4%	68.4%	70.9%
Sales % of Energy Purchased			78.7%	79.5%	80.0%	81.2%	81.9%	81.3%
Losses as % of Energy Purchased			21.3%	20.5%	20.0%	18.8%	18.1%	18.7%
Annual growth - Energy Purchased			-8.5%	10.6%	4.1%	6.0%	6.2%	6.6%
-KPLC Sales			-8.2%	11.5%	4.5%	7.8%	6.6%	5.4%
-REP Sales			-12.7%	8.0%	12.9%	2.0%	9.3%	13.5%

Notes:
1) Maximum output from the station under normal operating conditions.
2) Westmont was retired in September 2004 upon expiry of its contract with KPLC.
3) Emergency Power Producers were retired in June 2001. However, Aggrekko was commisioned in June 2006 under a new contract due to shortfall in generation foreseen in the Year.
4) System losses comprise of technical and non-technical losses.
5) The Demand shown includes the export demand. The Country's peak demand was 884MW and 916MW for 2004/05 and 2005/06, respectively.

source: Kenya Power and Lighting Corporation, Annual Report and Accounts 2005-2006

4.5 Focus on the target region: the Tana Water Catchment Area

4.5.1 Introduction

Geographically, the Tana Catchment Area is bounded by latitudes 0˚ 30′ North and 2˚ 30′ South, longitudes 37˚ 00′ East and 41˚ 00′ East. It extends from the crests of Mt. Kenya, the Aberdares Range, and the Nyambene Hills in the north extending southwards to the Indian Ocean bounded by the Yatta Plateau to the west and the Kenya-Somali border to the east. The catchment area covers of 126,000 square kilometers, with an estimated population of 5.5 million people, including agriculturalists living in the upper parts of the region and the pastoralists living in the lower parts of the region.

Mt. Kenya and the Aberdares Range, which are both gazetted and protected areas, are the main water towers of the region. providing 49 percent and 44 percent of the region's waters respectively. The remaining 7 percent is provided by the Nyambene Hills and minor catchments. The region provides more than 70 percent of Kenya's hydropower and 80 percent of the water consumed in Nairobi City, the Kenyan capital.

The Tana Catchment Area also includes several protected and gazetted areas, including four national parks and eight game reserves. The major ones are the Aberdares Forest, Mt. Kenya Forest, Meru National Park, and Tsavo East National Park.

The Tana Catchment Rehabilitation Report (by SCOTT&WILSON PIESOLD consultants) studied the rehabilitation & upgrading of hydropower stations in Kenya in depth. Their appraisal found that some 100,000 to 500,000 individual land holdings are contained within the Tana catchment area. This underpins the importance of soil conservation. The report concludes that "a reinvigorated, comprehensive and fully funded soil conservation program is needed" in the Tana basin. As per the recommendations, the implementation of such a program should follow a plan that sets targets and requires monitoring and reporting of progress. It is expected that the full implementation of such a plan might take some 15 to 25 years to complete.

While technical solutions to soil conservation are believed to be well-understood, the consultants consider that the willingness of many farmers and others to implement soil conserving activities will remain doubtful as long as local users do not receive monetary benefits for their active participation. The report advises that locally supported churches and pastors will be crucial for the compliance and acceptance among local users.

The incomes of farmers in the region have fallen sharply. In order to survive, farmers are increasingly neglecting their coffee and growing maize, potatoes, and other crops in rows between their coffee bushes. The ensuing land degradation crisis affects KenGen directly. Sound coffee husbandry practices have been largely abandoned by many small-scale farmers. As a direct result, soil conservation terraces, which are so characteristic of coffee growing areas on sloping land, have not been maintained. This has resulted in additional soil erosion with the development of deep gullies. Eroded soils are transported to intakes, canals, and tunnels at KenGen's small-scale hydropower stations and to the Masinga and Kamburu reservoirs.

The study ends by recommending that KenGen continue and further pursue its current interests in the World Bank's carbon funds. The report expects that "in due course, one or more of these funds may directly or indirectly assist soil conservation in the upper Tana basin and thereby contribute to reducing reservoir siltation and loss of electricity sales to the Kenya Power and Lighting Company (KPLC).”

4.5.2 Seven Forks Hydro Stations

Power generated from hydro energy currently forms 70 percent of the total electricity output. The company's hydropower stations have a total installed capacity of 680.88 MW. The power stations comprise the Seven Forks hydro stations, the Mini hydro stations, and the Turkwel hydro project.

These stations are situated along the lower part of the Tana River. They comprise: the Masinga Power Station, Kamburu Power Station, Gitaru Power Station, Kindaruma Power Station, and Kiambere Power Station. These five stations combined have an installed total capacity of 547.2 MW.

Water is being cascaded from one station to the next, taking advantage of the head created by each dam to produce power. To provide adequate flow during the dry periods, water is stored at Masinga Reservoir.

The Kiambere hydropower station with an installed capacity of 144MW; as it is currently fed by water from the lower dam on the Tana, the machines run mostly as base load.

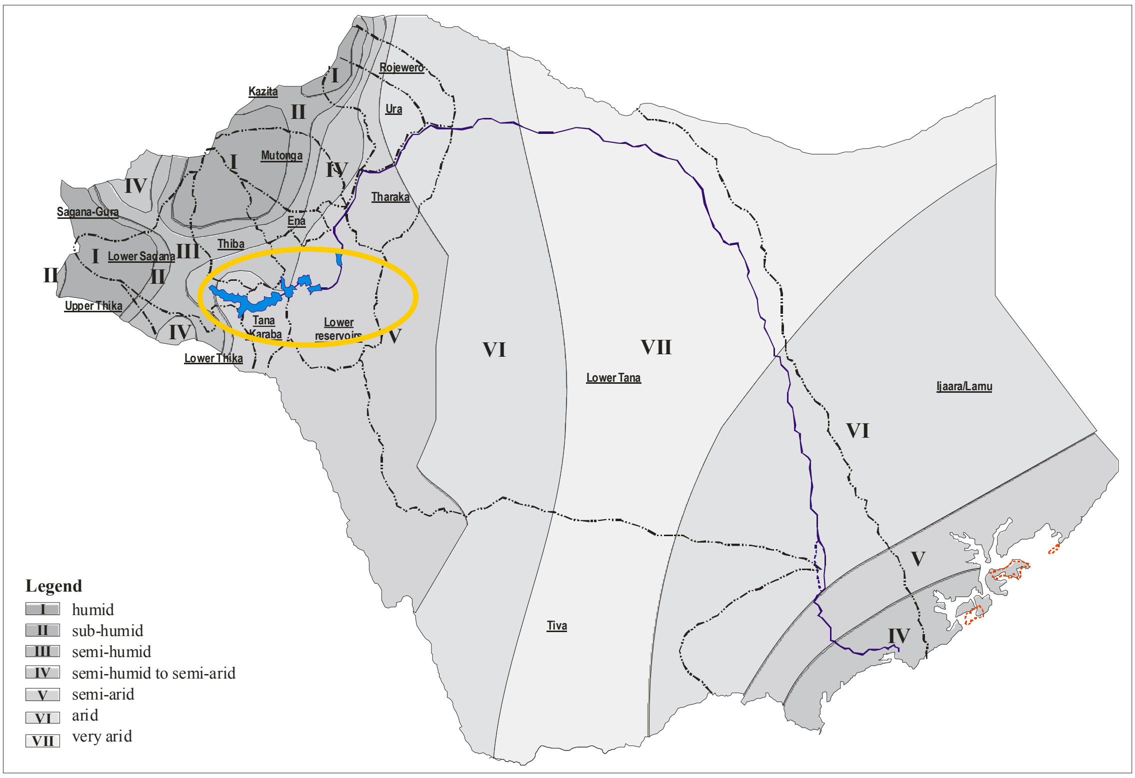
The Seven Forks have been providing about 65 percent of the country's electricity requirement. Two other sites along the river, Mutonga and Grand Falls, are yet to be developed.

4.5.3 Rainfall regime

Rainfall is bimodal, occurring during the long rainy season of March, April, and May, and the short rainy season in October and November. The classification of the agro-climatic map is built on the ratio of rainfall to potential evaporation. Figure 4 shows the relationship between the climatic zones and the natural vegetation and the potential and the risks for agriculture, assuming that soils are not the limiting factor.

According to the map, the Tana whole lower catchment—with the exception of the coastal zone—is classified higher than class V (semiarid to very arid) and the risk for agriculture is high to extremely high.

Figure 4. Climatic zones, natural vegetation, potentials and risks for agriculture in the Tana basin and the potential *Jatropha* project area (circle)



Zone	Ratio R/Ep (%)	Class	Rainfall (RF in mm)	Potential Evaporation (Ep in mm)	Vegetation	Potential for plant growth	Risk of failure to grow maize
I	>80	humid	1,100 – 2,700	1,200–2,000	moist forest	very high	extremely low (<1%)
II	65–90	sub-humid	1,000–1,600	1,300–2,100	moist forest & dry forest	high	very low (1–5%)
III	50–65	semi-humid	800–1,400	1,450–2,200	dry forest & moist wood-land	high to medium	fairly low (5–10%)
IV	**40–50**	**semi-humid to semi arid**	**600–1,100**	**1,550–2,200**	**dry wood-land & bushland**	**medium**	**low (10–25%)**
V	**25–40**	**semi-arid**	**450–900**	**1,650–2,300**	**bushland**	**medium to low**	**high (25–75%)**
VI	15–25	arid	300–550	1,900–2,400	bushland & scrubland	low	very high (75–95%)
VII	<15	very arid	150–350	2,100–2,500	desert scrub	very low	extremely high (>25%)

4.5.4 Stakeholders in a joint management of the Tana river basin

Table 5 shows the roles that various stakeholders play in the management of the Tana River basin. This table can serve as an institutional nucleus for an outgrower scheme involving production in the area and selling the feedstock to KenGen.

Table 5. Stakeholders and their roles in the management of the Tana River basin

STAKEHOLDER	AREA OF OPERATION	ACTIVITIES IN WRM	STAKEHOLDER 'S EXPECTATIONS
Water resources user associations	Drainage/subdrainage	Cooperative management of water resources Conflict resolution	Social and economic benefits from the water resource
KenGen	Muranga and Kerugoya subregions	Hydro electrical power generation, construction of water conservation structures	1. effective involvement in the management of water resources 2. reduced siltation as a result of well-managed catchments

Stakeholders and their roles in the management of the Tana River basin laid down in the Tana Water Catchment Strategy

4.5.5 Local institutions: the Water Resources User Associations

4.5.5.1 Introduction

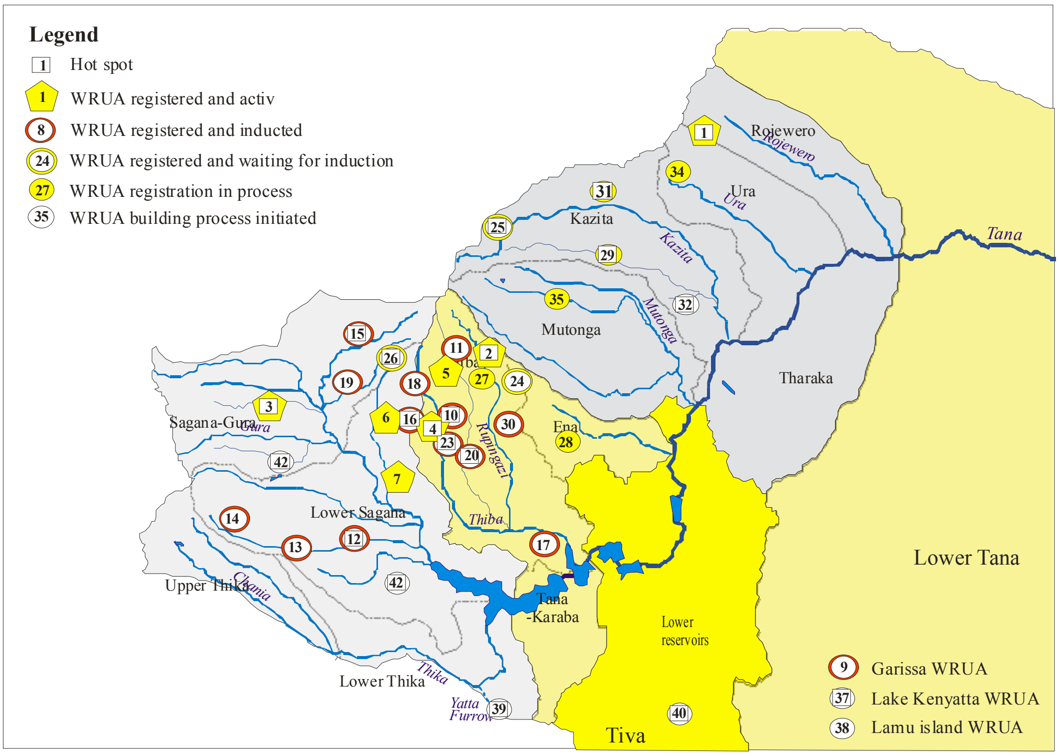
A new institutional framework has been established for Water Resource Management in Kenya under the new Water Act 2002. One of the main public sector institutions defined in the Water Act is the Water Resources Management Authority (WRMA), which has responsibility for management of the country's water resources.

At the local level, water resources user associations (WRUAs) are being formed with the support of the government and international assistance to ensure that water users participate in decision making concerning management of water resources in subcatchment areas. The WRUAs will play an important role in the prevention of conflicts over water. The inclusion of poor people, women, and other disadvantaged or minority groups in the WRUAs will be important to ensure that improved WRM will benefit all segments of the society

The availability of water is often a key factor in determining the patterns of human settlements and social and economic development. Within the arid and semi-arid lands, there is a critical limitation on water resources endowment. The limited endowment of water resources places an added financial burden on the Kenyan population compared with other countries.

4.5.5.2 Institutional development

Figure 5. Institutional Development of Water Resource User Associations as a Platform for *Jatropha* Feedstock Production



4.5.5.3 Financing Cycle of Water Resource Users Associations

Water is considered an economic good and therefore its provision should be at a cost. This calls for levying charges for water abstraction in its natural form to be commensurate with the amount abstracted. The amounts so generated will be used to meet the costs.

For WRMAs to meet the costs incurred during the performance of their duties, they need to raise revenue. Before the revenue is collected, there is a need to establish what the revenue is needed for and what process can be put in place to ensure availability of funds for planned activities. Based on the internal evaluation, WRMAs should be in a position to meet their operational cost by 2010.

However, it is reckoned that additional funding from key partners will be required to support and coordinate the communities in effective water resource management.

Figure 6. The WRUA Financing Cycle (1)

LEVEL 1: INITIAL SUPPORT TO WRUAS

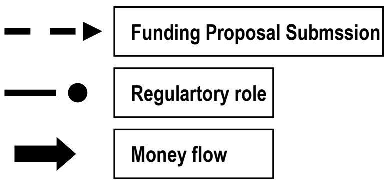
Funding support to WRUAs to prepare project proposals, for capacity building and for initial activities

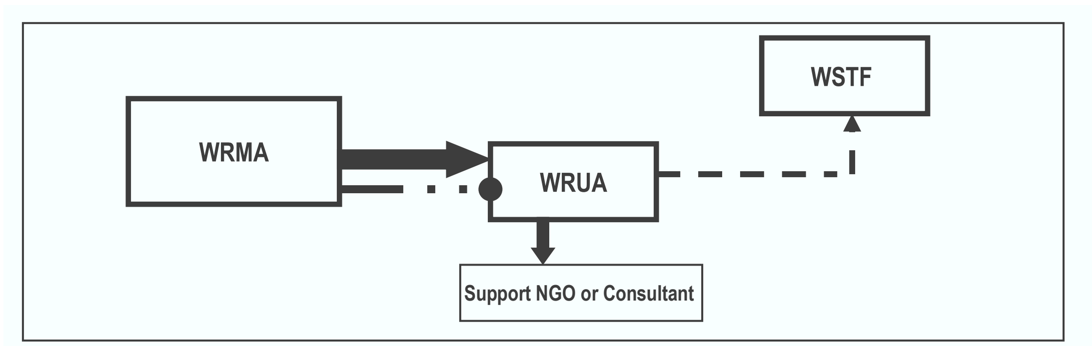
The WRUA Financing Cycle (2)

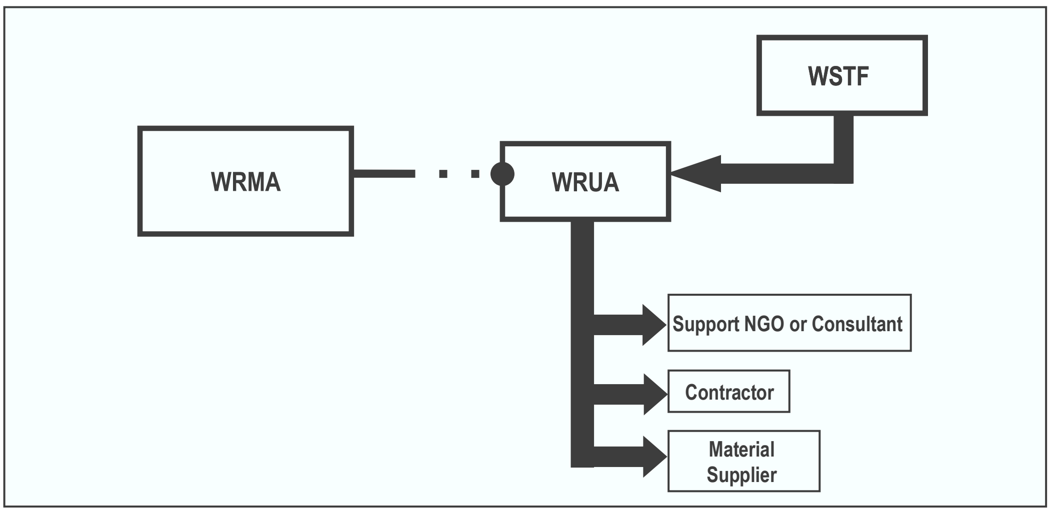
LEVEL 2: SUPPORT TO WRUAS FOR WRM ACTIVITIES

Funding support to WRUAs to develop water resource development activities, including storage structures

Legend:







ANNEX 1: LITERATURE

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