JATROPHA OIL PRODUCTION FOR BIODIESEL AND OTHER PRODUCTS

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A study of issues involved in production at large scale

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Developed in parallel with the Sudan Biofuels Roadmap project of the Aeronautical Research Centre (ARC_Sudan)

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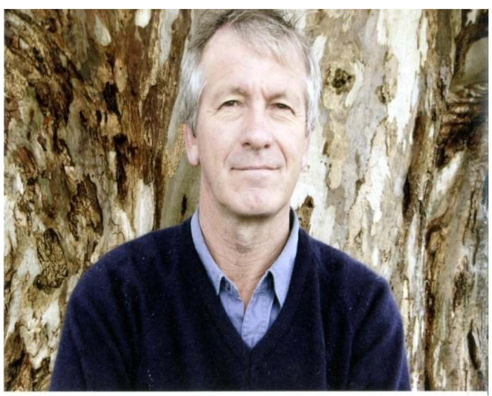
Disclaimer – while considerable effort has been made that the information in this report is accurate, the authors and ARC-Sudan stress that it should not be relied upon for making any financial commitment or policy decision or other commitment of any sort. It should only be used as a general guide, and as only one of many sources of information that should be consulted for making such policy or as a basis for any financial commitment.

Preface

This report examines the potential for establishment and management on a large-scale of the oil-seed producing plant jatropha (*Jatropha curcas*), primarily for production of biodiesel.

In reading over the extensive literature on jatropha it has been very obvious that too often many of the real issues critical to achieving a viable jatropha business have been obscured by wishful thinking or by a worrying level of ignorance of the fundamental requirements of any larger scale agricultural or horticultural production. Too often some ideological viewpoint has confused investment decisions. Too often unimproved seed was provided to outgrowers without apparent awareness that this would inevitably result in a variable and usually low yield.

So in this review we have largely ignored reports or publications that appeared not to be based on a sound approach. We have steered well clear of any study that promised yields or returns to investment that were clearly wildly optimistic. Instead we have where possible relied on basic principles of production, of agronomy and site assessment, and looked to establish detail and projections of actual economics and logistics.



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Preamble: Discussion of economic and logistical issues

Note – this section was originally directed at the labour costs, water and land availability and biodiesel needs of Sudan. Other countries will have different criteria, needs and costs, so will need to modify or converts some of the figures or assumptions that follow

For an investor or organization to enter into large scale production of jatropha oil any scheme or project obviously needs to be revenue-positive over time. Any investment on the scale needed may expect net annual return from year four (i.e., income to the project after all costs and interest on investment for that year) to be positive, so that by year 7 all initial investment is paid off, or, at the outside, that this is the case by year 10. Hence this overview of the economic and logistical aspects of the project assesses this possibility of this sort of rate of investment payoff, through making certain assumptions of costs, yields, etc.

Entering into a large scale agricultural enterprise involves developing a whole new array of agricultural practices and skills than what might normally be found in the country (one equivalent may be the changes necessary to support the palm oil industry expansion in Malaysia and Indonesia). It needs to be understood that there will be a period of possibly two years during which the necessary issues need to be mastered, the logistics understood, the trainee managers hired and trained, and the more sophisticated plant and equipment purchased. During this period nurseries will be set up in the plantation regions with the capacity to provide millions of seedlings of good genetic quality. There will need to be an army of people recruited and equipped to locate and assess, level, prepare and plant sites, and water new seedlings, as well as fence and plant shelter belts of trees.

This two year establishment and 'ramp-up' period will probably see planting of a number of pilot plantings of large-enough scale (50-100 ha?) to be used as training sites, as well as to allow testing of different planting and watering systems and to begin to provide the basis for settling on the logistic and economic best-bet options that need to be found. While industries like rubber, coffee, tea or oil palm growing may have taken up to 100 years to develop and evolve to their present state, the jatropha oil industry is likely now to begin in some countries only on the basis to 10 to 15 years of work. This entails some real risks for establishment of an enormous plantation estate that will be needed to supply the some part of the vast volumes of crude vegetable oil needed by the aviation, marine and land transport sectors.

For simplicity in the following calculations the unit involved is a 5000 ha 'block', or aggregate area of planting in a region or locality. It is unlikely that any single-management plantation will exceed 1000 to 2000 ha, though obviously total planted area in a region may in practice equal some multiples of this notional management 5000 ha block. These sites in one region are likely to share some labour and infrastructure and will certainly provide harvested seed into a common processing site. It is being assumed that a final area of jatropha plantings will be of the order of 125,000 ha, with the intention that this will provide about 150,000 tonnes of biodiesel to be used to provide about 5% blend of Sudan's 3 million tonnes of diesel consumption for diesel-engined transport plus stationary diesel-engined generators (the figures and assumptions for this follow).

Assumptions

- The jatropha project estate is 125,000 ha in blocks of 5000 ha.
- yields are 5 tonne of seed per ha by year five, and that the oil yield is 35%
- harvesting is partly mechanized and relatively efficient, resulting in cost of seed being approximately 10 cents/kg (US$100/tonne) at the gate of the pressing plant
- most sites have irrigation systems installed, so allowing 3 flowerings per year
- central processing plants are within 50 km of any regional grouping of plantation blocks, with each plant processing over 50,000 t dry seed per year.
- Adequate labour is available at a cost/day of US$4-5, and that housing etc., does not need to be provided.
- with manual harvesting an average of 50 kg/person/day is maintained
- Pruning is done to allow optimal fruiting and efficient harvesting manually or by machine.
- seedlings are of advanced genetics, growing to plants of good basic form, with more even ripening, and higher yields and higher oil content
- the seedcake byproduct of the pressing, and the glycerine by-product of the biodiesel production can be utilized and sold into either biogas production or compressed fuel production, at valuation of about $200/tonne for seedcake and $400/tonne for glycerine.
- Net production cost of oil is approximately $500, and international delivered price to Rotterdam is at least $1000/tonne.
- Pressing utilizes large capacity machinery including centrifuges, and that the oil is processed at low temperatures (below 60 C), and is stored and transported in optimal conditions, resulting in the necessary quality for efficient production of biodiesel.

The costs of establishing the project are previously advised to be approximately $2-3000/ha (or $10-15 million/5000 ha or $250-375 million/125,000 ha).

Note – the figures used in the following estimates of costs and returns are unavoidably approximate (those marked * are derived from quoted contract costs by Sudan Forestry Dept).
Figures of establishment costs are likely to be on the high side of what could be achieved with larger scale plantings. Figures for operational costs (irrigation and harvesting) may be low.

The break-down of estimated figures is shown in Table 1 and Table 2.

Table 1: Estimated Cost of Site, Establishment and Initial Infrastructure (Year 1)

Action	$ per hectare	$ per 5000 ha	$ per 125,000 ha
Land titles or contracts	20	100,000	
*Forming and leveling,	50	250,000	
Roading and fencing	500	2.5 million	
Establishment of windbreaks	100	500,000	
*Seedling	1000	5 million	
*Planting	500	2.5 million	
Drip irrigation system	750	3.75 million	
Fertilizing and weed control	50	250,000	
Site maintenance and security	10	50,000	
Hire cost of owned machinery (20% of value)	20	100,000	
Total cost	$3000	$15 million	$375 million

Table 2: Estimated Annual Operations costs (Year 2-3)

Action	$ per hectare	$ million per 5000 ha	$ million per 125,000 ha
Pruning	100	0.5	
Weed control and fertilizing	200	1.0	
Harvesting	100	0.5	
Irrigation	300	1.5	
Transport of labour and harvest	100	0.5	
Pollination services	20	0.1	
Site maintenance and security	10	0.05	
Hire cost of all owned machinery and pressing plant and shedding (20% of value)	50	0.25	
Total cost	$880	$4.40 million	$110 million

Harvesting will require very large workforce numbers from year 4 onwards. At a harvesting rate of 50kg/person/day, to harvest 1 ha (5 tonnes) in a day requires 100 people. At this manual harvesting rate 5000 people would take about 100 days to harvest the seed of 5000 ha (25,000 tonnes). To transport 5000 people every morning and night would take a fleet of perhaps 100 trucks or buses. Each site would possibly be requiring harvest at the same time – so any one harvest team may not be able to move to different sites. Obviously mechanical or faster, more efficient manual harvesting systems need to be developed as a matter of critical urgency.

It is assumed that until year 4 numbers of people employed in pressing plant and in harvest are relatively low, and that from year 4 onward these numbers rise to double the earlier numbers, with much of this labour being more highly trained and at higher hourly pay rates. So it can be assumed that after year 3 costs of storage and other shedding, transport required for removal of harvest and on-transport of oil, and movement of pressed seedcake, will all increase significantly. Many more vehicles and drivers will be needed, along with maintenance and servicing facilities, as well as oil testing facilities.

To transport the estimated 25,000 tonne of seed from each 5000 ha of plantings will require 2,500 return truck loads (assuming 10 tonne capacity), over a return distance of about 100 km, so entailing truck travel distance total of 250,000 km per harvest. Assuming at least 50,000 tonne of seed being processed at any one pressing plant the same or other trucks will be engaged in moving about 35,000 tonne of seedcake from this plant to some other site, and 15,000 t of jatropha oil to a central processing plant.

By year 4-5 the capacity of each pressing plant will need to be fully organised with any extra modules needing to be in place for pressing and oil storage. Further skilled and properly trained people will be needed for maintenance and servicing/overhaul etc., of pumps, presses, centrifuges and other equipment. Overall an assumption can be made that the costs of operation of the overall Jatropha plantation estate will be at least 50% more from year 4 onwards than in years 2-3.

This suggests a figure of over $160 million a year for operating costs from year 4 onwards when all 125,000 ha is in full production (for simplicity some calculations assume all establishment is done at once. In reality, establishment may spread over 10 years or more, and early plantings will be producing good yields well before later plantings go in. Overall economics may prove to be far better than shown here).

So can revenue from this estate of 125,000 ha cover all these costs, with a margin or surplus above this allowing the necessary certainty of achieving a payback of all costs by at least year 10? We can look at the estimated returns in year 5 assuming optimal management, adequate watering to each plant and a harvest per ha of 5 tonnes, and recovery from pressing and solvent extraction of 35% jatropha oil. Also some added income from a sale of seedcake and/or electricity and heat could be included. Summary of estimated gross revenue is shown in Table 3.

Table 3: Estimated Gross Revenue (Year 5)

Quantity or action	per ha	per 5000 ha	per 125,000 ha
Seed harvest	5 tonnes	25,000 tonnes	625,000 tonnes
Oil production	1.75 t	8750 t	218,750 t
Oil value @$1000/t	$1,750	$8.75 million	$218.75 million
Seedcake	3.25 t	16,250t	406,250 t
Seedcake Value @200/t	$650	$3,250,000	$81.25 million
Glycerin	0.12t	600 t	15,000 t
Glycerin Value @$400/t	$48	$240,000	$6 million
Total revenue	$2,448	$12,240,000 million	$306 million

Conclusion – given this estimated gross revenue of $306 million in year 5, at first sight it appears that the total establishment and infrastructure costs of up to $375 million, plus the annual operating costs for year 2 & 3 of $110 million/year, plus the operating costs for years 4 & 5 (and for ongoing years) of $160 million per year (including the pressing plant and extra transport etc.), will be recovered by year 10.

The gross income in year 5 (assuming the validity of values for seedcake and glycerine) is estimated at $306 million. It can be expected that yields will continue to rise beyond year 5 to plateau at year 10 and beyond. If a return on investment of 20% can be put on the initial establishment outlay this equates to about $75 million/year.

The cost of years 2 & 3 can similarly be treated as investment costs requiring a return of 20% - so about $45 million. Cost of operations in years 4 & 5 are together estimated at about $320 million, so 20% of this is $65 million/year. Assuming these figures are approximately accurate the total of all these investment and operations costs comes to $907 million outlayed before any significant income begins in year 5.

At a 20% per year expected return on capital and establishment/management costs, the calculation becomes more complex, as the various figures accrue annually and add to each other with each successive year, as in Table 4.

Table 4: Year-by-year investment outgoings totals for 125,000 ha estate (charging 20% on capital outlay)

Years	1	2	3	4	5
1	75				
2	75	22			
3	75	22	22		
4	75	22	22	32	
5	75	22	22	32	32
Total	375	88	66	64	32

*** 20% of investment at year 5 equals $615 million**

Gross revenue for year 5 harvest estimated at $296 million (year 4 harvest maybe break-even).

Thus it appears likely, at this high expected rate of return to investment (chosen to reflect the level of risks) and the relatively high costs assumed, that even when assuming steadily increasing yields from years five to ten, the investment will struggle to repay itself by year 10 – but appears likely to be income positive over a slightly longer time period. The situation improves if the expected rate of return is lower than 20% or some costs of establishment (possibly due to some external funds available in anticipation of carbon sequestration or deforestation mitigation aspects) and early management are lower than assumed, or income from harvest yields from as early as year 3 equal that year's outgoing costs (in the above breakdowns it assume this only happens in year 4).

And it needs to be said that this picture of the basic economic outcome is all before putting any positive dollar values on job creation, import replacement for fossil fuels, technology development, reduction in deforestation, carbon sequestration, reduced urban pollution due to micro-carbon particles from fossil diesel (and so reduced health care issues), and some possible reduction in rate of desertification. However it also needs to be appreciated that repayment of investment can also be affected by any of the following risks. While many of these are matters of management and training, some are involved with climate or other factors beyond ready control.

It is clear that having a number of processing sites, having jatropha plantation sites in many parts of the country, and a provision of a high degree of training of plant and equipment operators, will all be beneficial in spreading or reducing risk. It is assumed that the quality of sites, site preparation, seedling genetics and irrigation systems are optimized, along with ongoing work on harvesting, management, pollination systems, etc.

Risks

Failed or significantly reduced harvest due to any of a range of factors

- inadequate quantity or quality of water (including breakdown of irrigation pumps, etc)
- insufficient labour at harvest or for other time-critical operations
- mishandling of seed or oil- resulting in rise in free fatty acids, and fall in value
- mismanagement at sites re pruning, harvest, fertilizer, weed control or irrigation
- pests and diseases
- lack of pollinating insects
- climate extremes at flowering
- breakdown of processing or harvesting plant
- lack of trained personnel for pressing plant or other systems

Plus factors such as a fall in international prices of jatropha oil or biodiesel, or other adverse international developments and/or internal political problems

Upside factors

While the risks need to be considered, there are also a number of positive potential developments that also need to be factored into the overall view of this project and its short to mid-term economic prospects. These include –

- A significant rise in price of fossil fuels by 2020
- A rise in value of sequestered carbon by 2020, and of international interest in supporting projects of this type
- A major increase in demand for ‘sustainably’ produced vegetable oils suitable for biodiesel or aviation fuels, and so a significant rise in price of CJO or of processed biofuels
- Sale of quality seed or advanced genetics and expertise to other countries

Chapter 1: Genetics

Jatropha *(Jatropha curcas)* originates in Central America but was planted on large scale in the Cape Verde Islands before 1900, and was reportedly being grown there as early as 1836 (the FACT-Foundation's *Jatropha Handbook*). The harvested seed was exported to Europe principally to provide oil for soap making. In the 1920s and 30s up to 45,000 tonne of jatropha seed was being annually exported to ports in Europe. Seed shipped from Benin and Madagascar (other major sites of industrial-scale jatropha seed production) contributed to this volume.

From these initial sites jatropha has spread across many African countries to be mainly used for planting live fences. In general the oil was only used for folk remedies until the early 1980s, when the drive developed to find sources of vegetable oil for production of biofuels.

It was recognised from the beginning of the recent spike of interest in jatropha that the poor and variable genetics of the available plants was going to be a major limitation. Because of this work has been underway on genetic selection of *Jatropha curcas* from this period, while the plantings began of basically-unimproved jatropha at scale. In most cases these commercial planting ventures have since suffered financial collapse or significant loss of grower interest, due to much lower than anticipated yields and higher than predicted costs.

The most dramatic of these collapses have often not been well-publicised and the fate of up to 800,000 ha of proposed plantings in Myanmar (Burma) is a prime example. Often the largest plantings were the result of hurried development of national strategies to develop a biofuels industry (including in Myanmar, the Philippines and India). Many quite significant plantings also were stimulated or planted by well-intentioned NGOs, or newly-formed corporations that gained some government support in developing countries (such as Tanzania, Ethiopia, Malawi and Zambia).

Of these large plantings in the early 2000s most used fresh seed from mature acclimatised jatropha hedge plantings in the country or region. While some basic selection may have been done in collection of this seed or by setting up a seed orchard of cutting-grown mother plants, it was inevitable that a high degree of variability in yields was encountered as these larger-scale plantings came towards year five.

While forecast yields of up to 12 tonnes of seed per ha were being made in the development of many commercial plantings, in most schemes it was rare that yields approaching 1 tonne per ha were achieved, and not uncommon that seed averages per 5 year-old plant of under 0.2 kg were recorded (though oddly, there are many references in the literature of yields from mature hedges of around 0.8 kg per metre, which may suggest that very close planting of jatropha can result in a significant benefit for yield).

It needs to be stated that management and sites for this period of plantings were rarely optimal; most of these sites were rainfed and usually the plantings were established and managed by small-holders within part of their land on some harvest buy-back basis. Pruning, weed control and fertilising was often either rudimentary or non-existent.

Meanwhile genetic work on *Jatropha curcas* continues around the world. China, Vietnam, Indonesia, the USA, Australia, Germany, the Netherlands and Belgium are some of the countries where work has been done or is continuing on the development of improved strains of Jatropha. In Africa the main work appears to have been done in Ghana and Mali, but Kenya, Senegal, Tanzania and Zambia all have had some form of breeding and selection programs. The focus in all this work is on the same range of characteristics. These include yield (including selection for a lower ratio of male to female flowers in flower racemes) and improved oil percentages, non-toxicity of oil and seedcake, productivity at lower rainfall, and development of more even ripening to allow more mechanised harvest.

Already commercial jatropha management companies claim that on 'good' rainfed sites yields of 1.5 tonnes of oil from mature trees can be annually achieved on a regular basis. This requires yields of about 5 tonne of seed/ha from plantings over 5 years old.

The catch with this is that the 'good' sites are of quality soils and reliable rainfall in warm-temperate or sub-tropical regions, and so are suited to growing more valuable and productive crops. The aim of the people working on advanced jatropha varieties is that these will produce even greater yields on such sites and that economically acceptable yields will become possible on poorer or more marginal sites.

Some of the organisations known to be presently working on or involved with jatropha assessment, selection and genetic improvement include:

Jatropower AG Switzerland/Live Energies GmbH, Stuttgart, Germany

Quinvita NV, Ghent, Belgium

SG Biofuels, San Diego, USA

Surfactant and Bioenergy Research Center, Bogor Agricultural University, Indonesia

PolyGenomx, Queensland, Australia

Dept of Plant Breeding & Genetics, Jawaharlal Nehru Agricultural University, India

Centre for Jatropha Promotion (Jatropha World), Churu, India

As with all genetic selection programs, selection pressure on jatropha results in a rate of improvement that is fastest at the beginning. Several generations of breeding (where a generation should be no more than 2-3 years) should result in production of jatropha strains that have significantly more flowers in each cluster, a higher average yield per tree and per hectare at each harvest, higher average oil yields, and improvement in yields at lower rainfall and higher summer temperatures.

Large trial plantings of genetically-advanced jatropha cultivars are now happening, including in Guatemala, Mexico, Brazil and India. The companies engaged in this stage of development use various selection and breeding approaches and are often beginning with jatropha strains collected from different regions. Companies who can show that their strains have all the desired qualities for particular conditions will be able to recoup their investment in this development work many times over, and into the indefinite future.

The strains already exist that produce non-toxic seed, and so development of productive strains with this character should be relatively straight forward. However, the development of non-toxic jatropha strains (so potentially producing oil able to be used for cooking and seedcake for stockfeed), will also mean that the oil from this strain would be unlikely to be able to be used as a biofuel feedstock, due to the present rules governing sustainability of biofuels.

Chapter 2: Site choice, establishment and management

In reviewing the literature on jatropha plantings and management it is virtually impossible to draw conclusions or make valid comparisons between sites within even one country, let alone between sites in countries across a range of latitudes with widely differing soils, climatic zones, rainfall, management and average summer temperatures.

The main difficulty with making any comparison is that critical information is usually left out in each report. So, rainfall is given but not evaporation rate, soil colour or friability is given but no other soil test data, kilograms of seed per tree but nothing on oil percentage. And usually there is nothing on actual management (planting, fertilising and pruning), or on seed provenance. In effect many schemes have taken seed from 'wild' plants that have had not been selected for any of the desired characteristics, planted out seedlings at small scale on a multitude of smallholder plots with very mixed management, and have been surprised when it has had a low or highly variable yield.

So experiences to date with these past projects need to be largely discounted. The question needing to be answered is – *what is the potential and the conservative economics if jatropha is grown using best available genetics for yield and oil percentage, is planted on 'good' sites and managed properly, and grown at a scale allowing greater efficiencies, and where the harvested seed feeds into an efficient system of biodiesel production and full utilisation of by-products. And where all relevant broader issues, including the carbon aspects, the energy aspects and the issues of reduction of deforestation, are all addressed and, where possible, given real values.*

Site selection, establishment, management (irrigation and other aspects including climate and soils)

Although the influence of genetic quality of the jatropha plants has a major potential impact on average yield, to get this impact on yield and profitability requires close attention to the whole area of site choice, establishment and management (including watering). Each of these aspects must be optimised in order that a plantation will produce to the genetic potential of the plants.

It must be understood that a critical part of the choice of site is the climate at the site: the overall package of rainfall, average and extreme summer and winter maximum and minimum temperatures, prevailing wind, evaporation rate, wind-blown sand, and other climate factors including frost or likelihood of extreme weather events.

Some aspects of site choice can be moderated. So wind speed can be moderated by well-designed shelter belts, low or variable rainfall can be offset by well-designed and adequate irrigation systems, soil low nutrient levels can be remedied by added nutrients applied over the root zone, drainage can be improved by surface and subsurface drains or by mounding. But some qualities of the site cannot be moderated (except possibly at extreme expense) and these include maximum and minimum temperatures, soil depth, pH and salinity.

Site parameters

The 2009 report *Jatropha Reality Check,* written for Kenya by the World Agroforestry Centre, gives the following outline of conditions within which rainfed jatropha will grow, flower adequately and produce seed.

Parameter	range	optimal
Annual Temperature (0C)	12.7-33.3	19.3-27.2
Annual rainfall (mm)	440-3,121	1,000-2,000
Altitude (m)	0-1,800	
Soil	well drained, sandy, pH <9	

Soils and rainfall

While generally jatropha seems tolerant of a wide range of soil quality it is more likely – provided adequate water is available- to yield to its genetic potential in soils that allow good root penetration, have adequate levels of major, minor (including calcium, magnesium and sulphur) and trace elements, are neutral to mildly alkaline including at depths up to 2 metres, and are no more than slightly saline.

With regards to rainfall, jatropha is said in some handbooks to be stimulated to flower by good rains, and with regular rainfall can have up to three flowerings a year. Assuming this is the case, where rainfall is inadequate irrigation can be used to both provide adequate soil moisture for plant growth and seed development, and to trigger flowering cycles. However the *Jatropha Handbook* (in other aspects a usefully authoritative and prescriptive publication) says it is not clear what stimulates flowering but that it may be any one of a range of events that stress the plant.

It has been shown to be the case that jatropha will grow and produce at sites where the soils and climate are outside the range of what would normally be considered as productive sites for jatropha. So plantings in Egypt on sites near Luxor, and at Sohag and New Valley, irrigated with urban primary-treated grey water, are said to be currently producing 2 kg/tree on average (though present improvements in management aim to at least double this and potentially increase it 3 to 4 fold).

Another grey water-irrigated jatropha site at Giza near Cairo (using selected Indian seed) is said to be producing 4 ton/feddan (9.5 ton/ha) and being harvested 3 times a year (pers.comm), indicating that three flowerings per year are possible in a region where average summer temperatures are very high but that good watering system management seems to drive yield.

Obviously, adequate available moisture is an important determinant of yield, and yield is roughly correlated with rainfall up to some point. A study of *Jatropha curcas* strains collected from Central America and Mexico and from 83 plantations around the world found that jatropha 'does not occur naturally in regions with annual average precipitation of under 944 mm per year'. And that '…production in sites with 900-1200 mm rainfall can be up to double (5t/ha/yr) the production in semi-arid regions (2-3 t dry seed/ha/yr)'.(*Jatropha reality check*)

Establishment

Assuming the jatropha is to be planted evenly across the selected site, once the layout is decided along with any traffic routes, the preparation and establishment can start. Ideally the site is bare of all competitive plants except for any edge, shade or other intentional plantings. The planting should allow each tree the most space – so the most distance from each other. For instance, for a 3m x 3m planting this means that each row is staggered 1.5 m relative to the next, so in any two rows the plants on each side are alternate. This means each plant has a little more light access and root space.

While the convention with small-holder plantings has been to dig a hole for each plant and put some compost at the bottom and then plant the seedling on this, in practice on a sandy or sandy loam site the planting would be done at a far more rapid pace. With this soil type a hole is made only slightly larger than the plant pot or root bag, a slow-release fertiliser tablet possibly put in the bottom, and the plant put in, followed by thorough compaction of the soil and a covering of any surface of potting mix. In some instances – for example on drier or tougher sites - a water spear could be used to both form the planting hole and put some necessary water deeper into the subsoil layer. One suggested alternative is to plant 2-3 seeds at each spacing and keep only the best seedling that emerges.

Fertilising

Fertilising has been done for small-scale plantings by spreading of seedcake around the base of each plant. Several reports estimate the amount of nutrient removed from the site per tonne of seed harvested as equivalent to about 1.1 tonnes of chicken manure. An estimate by Centre for Jatropha Promotion (India) is that the seedcake has the nutrient value of chicken manure at nitrogen 6%, phosphorus 2.75% and potassium 0.94%, and that 1 tonne of seedcake is the equivalent in nutrient value as 200 kg of high nutrient fertiliser (NPK 12:24:12). An added benefit that the residual oil (up to 8% if only conventional screw-pressing is used) left in the seedcake may reduce nematode attack on the roots, and certainly the seedcake acts as a balanced fertiliser and a mulch, reducing moisture loss from this area and building up soil structure.

Planting spacing and planting layout

While it is assumed that the entire site is to be covered by a spaced planting of jatropha plants it needs to be emphasised that there are several other options. These include a mixed site use for jatropha and other cash crops, where the jatropha is then basically functioning as an edge or shelter planting, and/or belt or hedge plantings running through the site.

While a normal layout for jatropha may be 2m x 2m or 3m x 3m spacing (3m apart in the rows, with the rows 3m apart), with a cash crop possibly grown between the rows for the first few years, there is another option. This uses the jatropha as a shelter belt to the cash crop, and has narrow belts of 2-3 rows wide of jatropha with far wider alleys of 15-30 m wide between these of the cash crops. In this way humidity is maintained far better at ground level than on an unsheltered site, the site income may be less variable, the jatropha cycles deeper nutrient to the surface via its annual leaf fall, and it allows best use of the water from any irrigation system.

Layout needs to allow for quick access for all site management and for harvesting, and easy removal of harvested pods. Since the mature plants will fill much of the rows with foliage one option is to leave a wider alley (5-6m wide) every third or fourth row to allow for access by vehicles.

Also important is to consider and design into the layout regular points at which any vehicle might turn around. This can be easily done by having a wider transverse gap (5-6m) every 10 or 20 trees, thus allowing a vehicle to turn to one side or another and then turn again to go back up the next wide row it comes to. The saving in time and reduction of damage to trees from this simple design could be significant over a harvest period and during pruning, fertilising or pest control. Also in this way the entire plantation is divided into identifiable blocks allowing more organised management.

Plant growth optimisation

Many issues are involved in achieving good growth and yields from farmed plants, and while some are identified as being relevant for jatropha others are rarely if ever mentioned in the jatropha reports and handbooks. These include -

- Jatropha-specific mycorrhizal fungi that help roots access nutrient from soils (mycorrhizal associations with jatropha 'have been observed to be important' with growth particularly in P-limited soils)
- Any tendency of adjacent jatropha to root graft with each other
- appropriate spacing for mutual shelter and to reduce moisture loss from leaves
- type and numbers of pollinating insects at flowering
- sensitivity to low or high levels of trace elements (e.g., boron, molybdenum)
- growth limitation due to inadequate major soil nutrients (i,e,. N, P, K, Ca)
- presence of compaction layers or change in soil characteristic at depth

Irrigation

Irrigation delivery system choice

While jatropha was generally promoted as a plant that would produce on marginal sites in low rainfall regions this has been found to be not so. In such regions some irrigation has been found to be critical to achieving economic yields and getting more than one fruiting per year. In a study done for southern Morocco modelling irrigation requirement for jatropha (Sutterer, N, University of Hohenheim, 2010) it was found that irrigation volumes were required of up to 164mm in May and 156mm in June, falling away to about 40 mm between August and March.

Around the world there are only a few systems of irrigation used in horticultural plantings of this general layout. The principal ones are flood or channel (gravity watering), sprinkler, and drip systems.

Flood or channel watering requires an almost level site with a very even slight gradient into which watering channels or banks are formed. Either the channels would be either side of the tree line or down the centre of the alley. This system uses a lot of water, can result in overwatered and underwatered areas, and if overdone it can be associated with problems of salinity moving to the surface. The combination of slope and size of channel is critical in getting the right volume of water to every tree. Where soils are highly sandy and permeable channel irrigation would not be feasible for larger sites.

However, if soils are suitable, once the site is graded and formed this can be the cheapest to run. If this system is chosen it would be important to consider how to arrange the layout and traffic routes on the site to minimise compaction of wetted areas.

Sprinklers require high pressure and involve high water losses due to evaporation during hot weather. Because water is coming onto leaves and flowers from above this can cause problems, including spread of fungus or reduction in pollination, particularly if the water quality is not high. With sprinklers the weeds receive as much water as the trees do. It is a high cost solution usually used only with high value crops on relatively small areas.

Drip irrigation would appear to be the best and most obvious option for sites where water availability is limited, due to needing relatively low water pressure and volumes, and with the area watered being right at the area of the roots. Only each tree is watered and the weeds between and in the alleys are left without water. One drawback with drip irrigation is that insects or possibly mineral scale or suspended sand in the water will block some types of head. It is critical that the type of outlet is chosen to suit the water quality and other issues to do with the site. Drip irrigation would combine well with mulching around the trees to reduce soil moisture evaporation.

With drip irrigation for large scale plantings the choice is to have the lines buried or on the surface. Obviously with surface lines access is always simple for locating and fixing any blockage, but against this the evaporation rate from the wetted area can be unacceptably high, and line damage from harvesting vehicles, hoes, or other work can add to maintenance costs.

For a long lived perennial like jatropha, with a relatively deep root system and growing in a high evaporation rate region the other option is to use a buried line. The depth to which it is buried depends on soil permeability and would usually be between 20 and 30 cm. Roots are prevented from entering and blocking the nozzles by sending a charge of a suitable soil sterilant through the line so that a small sphere of sterilised soil surrounds each nozzle. This has to be done after the planting is done and soil has settled and after the soil is first wetted by a watering using clean water.

Cost of installing a drip irrigation system can vary greatly with figures ranging up to $4500/ha for systems in horticultural or vegetable production in higher labour cost countries. One major part of the cost is the small diameter distribution line which can cost around $1000/ha. Another large part of the cost is of pumping and filtering equipment .It is common for there to be a pump site for each 100-150 ha block. Equipment at each site can cost up to $80,000, though much of this is the computerised sensing and valve controls. The balance of the cost is mostly due to the labour for laying out and installing the system.

Issues to be considered as part of any irrigation system design

Positioning of the pumps, header tanks, fertiliser input tank or other infrastructure. Positioning of any isolator taps.

Friction losses in pipes, and choice of pipe diameters, tap materials and joiner designs. Maintenance and durability of components.

Type, design and maker of pumps and motors.

Source of power for pumps and its reliability

Water volumes required per ha and per total area

Pests and diseases

Contrary to the optimistic assurances in some handbooks jatropha is subject to attack by a range of pest and diseases, though this tends to be more of a problem with larger-scale plantings in climates with high humidity and higher rainfall. While control of pest insects and fungi may require chemical sprays in higher rainfall regions, it is possible in a semi-arid region that a natural control regime is adequate. This includes maintaining populations of insect-eating birds and of predatory insects at the site by planting a well-chosen mixture of species of shelter-belt plants.

For instance in Zambia insect damage in a jatropha plantation is said to be reduced by the strategic planting of Tephrosia vogelii (fish poison bean), the leaves of which contain a very high concentration of rotenoids. The feeding by guinea fowl or domestic poultry has been part of keeping insects including termites controlled in some smaller plantings.

However it is the nature of monocultures of any plant that they are far more likely than a few scattered plants to suffer insect, fungus or nematode attack at some time. It is necessary to be aware of the various pests and of their likely damage and of the response needed. Good management will include regular monitoring of all parts of the site, and particularly if the plants are under any stress due to temperature, moisture shortage, or nutrient inbalances.

Pruning

The advice given in various reports and handbooks is to use pruning over years 1-3 to form each jatropha so that the branches are spaced to give best distribution for fruiting (and so exposure to light). In general the advice is to prune so the jatropha is about 2 metres tall and is approximately round with branch ends allowing even penetration of light to all fruit bunches.

In the case of hedges no mention is made of pruning, but it appears that the individual jatropha plants in hedges are relatively suppressed and branches do not usually extend more than a metre from the hedge line. However the hedges are often credited with quite high yields of seed, with a figure of 0.8 kg per metre and so up to 800 kg per kilometre.

Pollination

Jatropha is insect pollinated, and to achieve optimum yield requires presence of suitable numbers of nectar-feeding insects at the time of flowering. To assist with this growers have brought in beehives or planted other flowering trees around the jatropha plantations. These have to be of species suited to the climatic zone, and possibly that can supply some side products of wood or fodder. Flowering edge species may be indigenous or imported species that are preferably non-invasive. Another important attribute is that they are not going to negatively affect the jatropha either by scavenging soil moisture or chemically suppressing jatropha growth.

Figure 1. Jatropha fruits – note variable ripening

Figure 2. A 3 year old jatropha showing possible fungal canker infection

Figure 3. Intercropping of maize with jatropha in Zambia

Chapter 3: Harvesting and storage

Harvest process

For many jatropha plantings reported on in the literature, up to 80% of the cost of production of jatropha seed was made up by the cost of manual harvesting. Obviously, as with all other hand-harvested crops, cost of harvesting/unit weight is affected by many variables, including -

- amount of fruit per tree, number of fruit in each bunch, and weight of seeds
- accessibility of fruit to the picker – so the conformation and height of the tree
- evenness of ripening (so number of repeat visits to each group of bushes or trees, in order to collect the seed produced from any one flowering
- collection process – efficiency of collection of harvested seed from pickers
- payment system (whether per hour or by weight picked per day)

It is said that the production of jatropha is inevitably handicapped by the uneven ripening process of the fruits. However producers of many other horticultural or food crops or other plant product picked or gathered by hand have evolved systems that in various ways improve the efficiency. Examples include coffee, tea, tobacco, fruits, nuts, berries, many vegetables, mushrooms, grapes. Some of these have a unit value for the producer that is quite low – as with jatropha – and yet manual harvesting is still economically possible due to development of various innovations or efficiencies.

This may be by the way the produce is accumulated and carried by the picker, it may be how the picked material is rapidly transferred to the bins or other removal system, and it may be by some semi-mechanised system that might carry the pickers. In some cases the conformation of the plants to be harvested have also been changed to suit some more efficient system of harvesting. The trellising of grapevines is an example.

Evolution of more efficient approaches may similarly be developed with jatropha. For example the customary method is to grow plantation jatropha, ideally with some early pruning, into a round bush at maturity of about 2 metres high, with seed production at the ends of branches all around the circumference. For a picker to collect all seed will require collection from an area of at least 1.5 metre top to bottom around 6 metres of circumference. This means each picker has to collect ripe fruits from up to 100 fruit bunches among up to 10 m2 of foliage. With 800 to 1000 seeds per kg greenweight, and perhaps 2000 fruit (ripe and unripe) on a tree, the time taken per tree is obviously considerable even when a good picker is being paid by weight collected. The 2009 report *Economic viability of Jatropha curcas in Northern Tanzania* provides some figures on harvest rate in the literature. These range from 3 Kg/hr (Henning 2004, for Mali) to 2-10 kg/hr (Eijck 2007). It has to be assumed that the very low rates per hour reflect very low yielding (possibly quite young) trees across the plantings of a number of smallholders.

Other sources give somewhat higher figures. The figure mentioned in the case study on Diligent in Tanzania (Eijck 2009) is of an average of 40 kg/day by small holders. On the Jatrophaworld.com website a figure of 8 kg/hour is given for harvesting from high yielding plants. The best overview on real harvest volumes/time across a number of countries is in the *Jatropha handbook*.

While the quality, spacing, age and yield per tree are not given these harvest rate figures appear low for production of a feedstock for any commercial biodiesel production. Even at a very low labour cost Wiskerke (2008) estimated it meant that, including all other site costs, and including shelling or dehulling, the cost of production of jatropha seeds was about US$0.10 per kg.

This must be factored against the fact that the cost of jatropha oil on the world market in 2012 delivered to NW Europe was around US$1000/tonne, comparing with edible oils like palm oil at about US$1200 and soybean oil at about US$1000. At a yield of 30% this translates to about US$300/tonne for dried jatropha seed (making some allowances for pressing and transport), and so possibly the maximum total cost of production for seed per dried kg at the pressing plant might be US$0.015 to provide an adequate return on equity to an investor.

On any commercial scale harvesting has to become many times more efficient – so that many times that seed volume is harvested per hour, and at less than this cost/kg. One possible option for making harvest more efficient is to form-prune all bushes in a row so that, if viewed from above, each bush is much more rectangular than round (essentially with each row becoming a thick hedge). This will allow plants in a row to be closer together, seed is borne on an approximately flat surface, and so it gives an option for pickers to be carried on a motor-driven platform with both sides of the row being picked at once, and with picked fruit going immediately to storage containers carried on the vehicle. This same pruned form is more suited to mechanical harvesting. One possible negative of this is that the 'wood' of a jatropha plant is not inherently very strong and a round form of bush would be less prone to breakage in severe winds.

Handling and storage

Once the yellow or blackened fruits are picked and collected they need to be efficiently handled, dehusked or decorticated, rapidly dried, and the seed stored or transported in suitable containers. If some of these processes are not done well a number of things can occur. One is that the free fatty acid (FFA) content of the oil in the seeds can rise from its initial levels of below 1% to higher values. If this happens the cost of producing biodiesel from the oil will begin to become more complex and costly. As FFA values rise above 1%, if the standard alkaline-catalyst transesterification reaction is used, the result will be increasing degrees of formation of soapy residues and foaming. Introduction of a preliminary stage of acid-catalyst processing (esterification) to avoid this may result in the percentage yield of biodiesel per litre of jatropha oil dropping from the low 90s to the low 80s, with the process becoming slower and so more costly.

The recommendation in various publications is that the fruit is spread to dry in a dimly-lit airy place. With far larger volumes being handled the drying and dehusking will need to be a mechanised process. Systems for this are reviewed in the *Jatropha handbook*.

For most oil seed crops the seeds are promptly pressed, with moisture content being removed from the fresh oil later. This is the process used for pressing palm oil and for many other vegetable oils. It is unusual in a large commercial processing system that the seed is thoroughly dried before pressing – though some seeds may be very low in moisture content, i.e., canola/rapeseed and cotton seed. However the recommendation for jatropha is that the moisture content ideally is between 2 and 6% for best results when pressing (*Jatropha handbook*).

If the seed is to be kept for propagation the recommendation in the literature is that it is stored at around 6 ^{0}C in sealed containers or a low humidity environment. Viability of the seed in good storage is said to be relatively unchanged for up to a year. However some cases have been reported of seed bought for propagation having a very low germination, and this is probably due to storage in poor conditions or being kept for too long – or a combination of both.

Figure 4. Jatropha seeds – about 1300 dry seeds per kg. Average harvesting rates are 40-60 kg per day per person from higher-yielding jatropha bushes

Chapter 4: Oil pressing and biodiesel production. Alternate biofuels production

With large scale production of jatropha volumes from any one site or region may be pressed and processed into biodiesel locally or regionally, or the seed or oil may be taken to some central site for more efficient larger scale processing. The approach to convert rapeseed oil to biodiesel in Germany or Sweden, or to convert soy bean oil to biodiesel in USA or Argentina could serve as models for this for the scale required, monitoring and testing, removal of oil from seedcake, water content, etc.

For conversion of jatropha oil into 'drop-in' diesel or other synthesised fuels such as aviation fuel, this would normally be done using similar processing approaches and plant as for a relevant part of the crude oil refining system. So, Neste Oil's plants for converting vegetable oils such as palm oil by the hydro-treatment process at refineries in Porvoo Finland, Singapore, and Rotterdam could be looked at. This process results in a diesel substitute that is closer in its characteristics to fossil diesel than transesterified vegetable oil (biodiesel) is.

Oil pressing

Machinery is commercially available for pressing of vegetable oils from seeds at all levels of volume. Where seed harvest plantings of 1-2000 ha on any one site in a region can be aggregated together it may only come to less than 50,000 tonnes/year, and with this arriving in only one or two periods of a few months each. Because of the relatively small scale of this and the need to press oil soon after harvest it may be economic to press locally but transport the oil to the central biodiesel production facility. To maintain a press at work a suitable storage system needs to be available for the harvested seed. A part of this decision relates to the disposal or use for energy of the up to 30,000 tonnes of seedcake produced at a site receiving 50,000 tonnes of seed.

Solvent extraction

Screw press equipment leaves 5-8% of oil in the seedcake. This can be largely removed by a solvent extraction process, and so at least 5% extra added to the real yield of oil per unit volume of seed. According to Centre for Jatropha Promotion this becomes cost-effective at processing of over 200 tonnes/day, so in a processing centre drawing on 7000 ha of plantings or more.

Criteria for deciding location of pressing

There are a number of criteria for deciding at which geographical location to press the oil from the seedcake. Some of these will have greater impact on overall economics than others:-

- Scale of machinery at which highest efficiency of pressing to get best fraction of yields occurs (see above comment on solvent extraction)
- Location of further use or other processing of seedcake
- Issue of return of nutrient to jatropha production site and cost of transport
- Locations of synergistic industries for seedcake/oil/biodiesel/heat production
- Labour costs and other overheads with regional vs centralised pressing
- Benefits of jobs created in rural region

Biodiesel production processes

While very small scale production of biodiesel (up to a few hundred liters at a time) will be done by processing one batch of oil at a time, the larger scale biodiesel production process is a linear process. It involves a set flow rate of filtered vegetable oil being mixed with a calibrated sidestream of usually sodium or potassium methoxide, and heated. After a set holding period the resulting liquid is washed to remove remaining catalyst and then separated into the biodiesel stream and a glycerin by-product stream. The separated is effected by utilising the different specific gravities of each of these components, with the biodiesel being significantly lighter than the glycerin.

Technical issues in production of straight vegetable oil (SVO)

A number of issues are involved in production of a high standard or quality of clean vegetable oil. It is important to minimise the movement of phosphorus compounds (including phosphatides, phospholipids) from the seedcake into the oil and partly this is related to keeping temperatures in the pressing system from going about a certain point – *The Jatropha Handbook* suggests this temperature is likely to be 55-60^0 C.

Removal of particles is by filtering or centrifuging. At the volumes likely in a commercial production in Sudan the use of a centrifuge appears most appropriate. Water is one of the non-oil compounds that also have to be removed as the content of water in SVO has to be kept below 0.08%. Higher water content potentially results in oxidation of the oil in storage and a rise in content of free fatty acids.

Storage and transport of SVO has to be in containers with minimal oxygen or water vapor – so in containers that are full (or where the empty space is filled with nitrogen or a similarly inert gas) and with vapor-lock or airtight caps. In general quality of stored or transported oil should be kept cool – below 30^0 C- to minimise activity of plant enzymes that cause auto-oxidation (*The Jatropha Handbook*).

Due to the toxic phorbol compounds it contains handling of jatropha oil needs to be done with due care, using precautions against it getting into eyes or onto other mucous membranes including inside the nose, mouth and digestive system (*The Jatropha Handbook*).

Transesterification Process

Transesterification is regarded as the best method among the alternative biodiesel production methods, due to its low cost and simplicity. Transesterification is the normal name given to the chemical reaction between triglycerides and alcohol to form an ester and glycerol with or without the presence of catalyst. Most of biodiesel production technology are adapting transesterification of oil as triglyceride by short chain of alcohol mostly methanol (Figure 5). In transesterification of jatropha oil which has a wide range of Free Fatty acid (FFA) content which are beyond the optimum level for alkaline transesterification to occur, two step reaction is conducted to allow maximal conversion which is needed to gain standard specification of ester content. The first step is pretreatment to decrease the FFA to less than one. Then oil with low free fatty acid from pretreatment unit is reacted with methanol using KOH/NOH as catalyst. The excess methanol can be recovered in designing of large scale systems of biodiesel production from each process step. The crude glycerin is also can be recovered as by-product.

The transesterification reaction is affected by various parameters depending upon the reaction conditions. If the parameters are not optimized either the reaction is incomplete or the yield is reduced to a significant extent. Each parameter is equally important to achieve a high quality biodiesel which meets the regulatory standards (Lay L 2009). And the maximum yield of biodiesel should be at the optimum values of these variables. Some of the critical variables are molar ratio of alcohol to oil, concentration of catalyst, reaction temperature, and reaction time.

In large scale production of biodiesel from crude jatropha oil (CJO), while the CJO is the largest input cost, the costs of the other chemicals used are also significant. Optimizing the amounts of these chemicals along with other parameters of reaction temperature and time indicate that real savings can be made in time and chemical cost, which significantly improve operating economics.

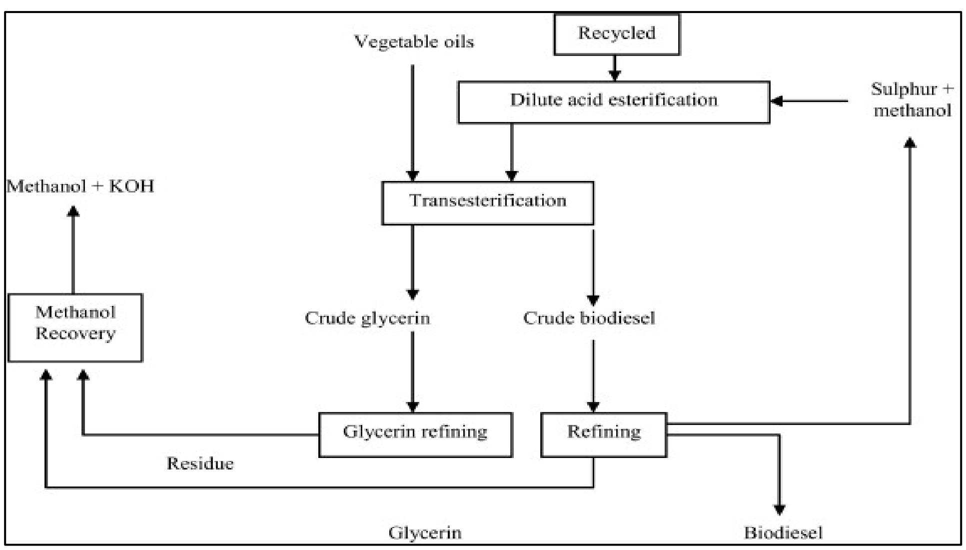

Figure 5. Basic schemes for biodiesel production *(A.S. Silitonga et al. 2012)*

Biodiesel fuel standards

European Standard for biodiesel (EN 14214) and the American Standard Specification for biodiesel (ASTM 6751-02) are the two major international biodiesel standards followed all over the world where the characteristics and qualities of biodiesel such as the flash point, kinematic viscosity, specific gravity, free fatty acids and acid value have been introduced (Kahraman Bozbas; 2005). Table 5 shows detailed ASTM D 6751 and EN 14214 biodiesel specifications, while Table 6 shows comparison of fuel properties of jatropha oil, jatropha oil methel ester and diesel fuel according to ASTM D6751 and EN 14214 standards.

The cost of Bio Diesel is largely dependent on the choice of feedstock and the size of the production facility. Capital costs for biodiesel production facilities are similar to those for ethanol facilities, ranging from $9,800 to $29,000 (2004 dollars) per daily barrel of capacity, depending on size of the production facility. Further it is largely dependent on the choice of feedstock. If Jatropha feedstock is used, the fuel will cost (depending on the country) approximately US $ 0, 40 per liter, plus any taxes.

Table 5. Biodiesel Specifications and test methods of ASTM D6751 and EN 14214 standard,

(Dennis Y.C. et al. 2010)

Property	Unit	Limits		Test method	
		ASTM D6751	EN 14214	ASTM D6751	EN 14214
Flash point	°C	130.0 min	101.0 min	D93	ISO CD3679e
Kinematic viscosity at 40 °C	mm^2/s	1.9–6.0	3.5–5.0	D445	EN ISO 3104
Cetane number	–	47 min	51 min	D613	EN ISO 5165
Sulphated ash content	% (m/m)	0.020 max		D874	ISO 3987
Copper strip corrosion	–	No. 3 max	Class 1	D130	EN ISO 2160
Acid value	mg KOH/g	0.80 max	0.5 max	D664	pr EN 14104
Free glycerol	% (m/m)	0.020 max		D6584	pr EN 14105m pr EN 14106
Total glycerol	% (m/m)	0.240 max	0.25 max	D6584	pr EN 14105m
Phosphorous content	% (m/m)	0.001 max	0.01 max	D4951	pr EN 141101
Carbon residue					
ASTM D6751 (100% sample)	% (m/m)	0.050 max	–	D4530	–
EN 14214 (10% bottoms)		–	0.3 max	–	EN ISO 10370
Cloud point	°C	Report customer	–	D2500	–
Density at 15 °C	kg/m^3	-	860–900	-	EN SIO 3675 EN SIO 12185
Distillation T90 AET	°C	360 max	–	D1160	–
Sulfur (S 15 Grade)	ppm	0.0015 max	–	D5453	–
Sulfur (S 500 Grade)	ppm	0.05 max	-	D5453	-
Sulfur content	mg/kg	–	10 max	–	–
Water and sediment	%vol.	0.050 max	–	D2709	–
Water content	mg/kg	-	500 max	-	EN ISO 12937
Total contamination	mg/kg	–	24 max	–	EN 12662
Oxidation stability at 110 °C	h	–	6 min	–	pr EN 14112
Iodine value	–	–	120 max	–	pr EN 14111
Linolenic acid methyl ester	% (m/m)	-	12 max	-	pr EN 14103d
Polyunsaturated (≥4 double bonds) methyl esters	% (m/m)	–	1 max	–	pr EN 14103
Ester content	% (m/m)	–	96.5 min	–	pr EN 14103d
Methanol content	% (m/m)	–	0.2 max	–	pr EN 141101

Table 6. Comparison of fuel properties of jatropha oil, jatropha oil methyl ester and diesel fuel, *(Dennis Y.C. et al. 2010)*

Property	Unit	Jatropha oil	Jatropha oil methyl ester	Diesel	ASTM D6751-02	DIN EN 14214
Density at 288 K	kg/m^3	918	880	850	875–900	860–900
Viscosity at 313 K	mm^2/s	35.4	4.84	2.60	1.9–6.0	3.5–5.0
Flash point	K	459	435	343	>403	>393
Pour point	K	267	267	253	–	–
Water content	%	5	Nil	0.02	<0.03	<0.05
Ash content	%	0.7	Nil	0.01	<0.02	<0.02
Carbon residue	%	0.3	0.025	0.17	–	<0.3
Sulfur content	%	0.02	Nil	–	0.05	–
Acid value	mg KOH/g	11.0	0.24	0.35	<0.8	<0.50
Iodine value	–	101	104	–	–	–
Saponification value	–	194	190	–	–	–
Calorific value	MJ/kg	33	37.2	42	–	–
Cetane number	–	23	51.6	46	–	–

Storage of Biodiesel

The efficient storage of biodiesel resources can provide energy security to the country. Adequate data are not available for long-term storage of biodiesel and blends. Based on the experience, biodiesel can be stored up to a max. 6 months.

As a mild solvent, biodiesel tends to dissolve sediments normally encountered in old diesel storage tanks. Brass, teflon, lead, tin, copper, zinc etc. oxidize biodiesel and create sediments. The existing storage facilities and infrastructure for petrol & diesel can be used for the biodiesel with minor alterations. For biodiesel storage, shelf life and how it might break down under extreme conditions assume importance. The following merit attention for storage of biodiesel:

- Biodiesel has poor oxidation stability. Use of oxidation stability additives is necessary to address this problem.
- Low temperature can cause biodiesel to gel, but on warming it liquefies quickly. Hence, insulation/jacketing of storage tanks and pipelines would need to be done at the low temperature zones.
- To avoid oxidation and sedimentation of tanks with biodiesel, storage tanks made of aluminium, steel etc. are recommended for usage.

(information as given in www.jatrophaworld.org).

Volumes and logistics

In the case of Sudan, in order to produce 5% of the current diesel use of about 3 million tonnes, about 150,000 tonnes of biodiesel must be made. At a conservative 80% conversion rate this will require about 187,000 tonnes of jatropha oil. At a 30% yield to produce this will require up to 625,000 tonnes of jatropha seed, and about 436,000 tonnes of seedcake will be the by-product of the pressing. About 15,000 tonnes of glycerine will be the main by-product of the biodiesel production process.

These are very large tonnages and volumes, and obviously aggregating all the seed in one spot, and transporting all pressed seedcake away from one spot will be major logistic issues, and the transport of all this material will require a significant amount of diesel fuel.

The production of this volume of seed even at relatively high annual yields of 5 tonnes/ha will need about 125,000 ha of well-managed jatropha plantation. In practice the jatropha plantations will tend to be of no more than 1-2000 ha in size and there may be between 60 and several hundred in different locations spread out across the country. For some the seedcake will be used locally for generation of electricity and industrial heat, and for others the volumes of seedcake may lend to use as a substitute fuel for wood in brick kilns for other large-scale industry users.

Production of synthetic diesel using gasification and reforming.

At some scale the technologies of production of synthetic fuels from carbon-rich agricultural residues may be cost-competitive. This technology in theory allows any agricultural or timber industry processing residue to be used as a feedstock. For example the Fischer-Tropsch process developed in Germany in the 1920s was used by South Africa during the apartheid sanctions era to produce mainly diesel fuel from coal. It was previously used in Germany during World War Two to produce diesel and petrol, again using coal as the feedstock. In practice with an adequate volume of biomass residue like jatropha seedcake the same process could be used to produce synthetic diesel or aviation fuel, or other long chain organic compounds including plastics.

Figure 6. Small jatropha oil extraction machinery being used in Zambia

Figure 7. Crude jatropha oil filtering systems in use in Zambia to produce oil clean enough for fuelling modified diesel motors (in pumps and generators) and vehicles

Chapter 5: Biogas from jatropha seedcake

Jatropha seedcake – as with all forms of seedcake, including from castor oil plant – is a possible feedstock for biogas production. The residue of the anaerobic fermentation that produces the biogas is a high nutrient-content sludge with an equal percentage of most plant nutrient components on a dry weight basis as the original feedstock, but with the initial levels of jatropha oil, proteins, sugars and other fats fully utilised by the micro-organisms that have produced the biogas.

However this Jatropha Report suggests that the economics of using the seedcake for biogas production with the residues being dewatered and returned to the plantation may be of equal or higher economic value than any other option, when the value of nutrient return is included in the calculation along with transport costs.

According to a personal communication one tonne of jatropha seedcake will produce 170-250 m3 of biogas of about 60% methane (and so with an energy value of about 6 kWh/m3). The glycerine by-product of biodiesel production in this volume while having an international trading value may have few other uses within many countries but it also is known to be a good quality feedstock for biogas production.

Production of biogas requires a well-managed system consisting of mixing tanks, one or more insulated reactor tanks, a holding tank for the residue, and the biogas treatment scrubber and dewatering stage and a gas engine-driven generator for conversion of the biogas into electricity and heat.

The seedcake needs to be arriving at the biogas plant regularly and not held at other sites. Development of fungus will occur in wet seedcake held at other than very low temperatures (below 6^0 C), and the fungus will both degrade the seedcake and pose a health hazard to anyone handling the seedcake. It is possible to dry the seedcake to prevent this but with the large volumes involved this is unlikely to be cost-effective.

In addition to the regular new feedstock the reactors need to have a regular input of water. Normally with anaerobic digestor management a new mix is added on a daily or even hourly basis from the mixing tanks, with water making up perhaps 90% of the infeed volume. At the same time as this happens the residue that has no nutrient value for the microorganisms anymore is drawn from the bottom of the reactor.

It is clear that the scale of this anaerobic digestor (AD) allows for employment of people to continually monitor and maintain the system. In effect such a system processing 60-80,000 m3 a year of the 10% dry matter mix of seedcake plus glycerine could fuel a gas motor-driven generator year-round producing 1-2 megawatt (MW) of electricity.

So for each 6000 tonne of seedcake (so about 60,000 m3 of infeed at 10% DM) at least a megawatt of electricity and up to 2 MW of heat are produced. From the jatropha pressed seed providing the proposed supply of biodiesel to make up 5% of 3 million tonne/yr of diesel about 430,000 tonne of seedcake will be produced. In theory this amount could produce enough biogas to generate in excess of 70 MW of electricity and at least 140

MW of heat. The volume of about 15,000 tonnes of the glycerine by-product from the manufacture of 150,000 tonnes of biodiesel would add significantly to this output.

In some cases streams of uncontaminated sewage or food processing residues could also be part of the in-feed to some digestors. The attraction of this use of jatropha seedcake to produce biogas and thence electricity is that it could be mainly in regions previously reliant on diesel engine-driven generators. Supply of water to maintain the flow through the AD would be grey water coming from the communities served by the electricity supply.

Cost of anaerobic digestors. Cost of digestors can range from the cost of materials and labour for a lined in-ground tank system for a household or group of houses, up to US$5-8 million for a system processing 60-80,000 m3 a year of diluted seedcake. These larger systems produce biogas that after dewatering and removal of hydrogen sulphide goes directly to fuel a gas engine driving a generator. The household system would normally be producing gas used only for cooking and possibly lighting and cooling.

Value of AD sludge as recycled nutrient. The residue from an anaerobic digestor has almost the same nutrient value on a dryweight basis as the feedstock. The principal fractions used by the bacteria that are the active producers of the biogas are the fats sugars, starches and oils, most of which would quickly decompose if the seedcake is put out untreated as a fertiliser-mulch. In addition any proteins would be utilised by the bacteria. So while the nitrogen level of the residue is lower than that of the feedstock, the levels of major nutrient – phosphorus, potassium, calcium – and of the trace elements would be essentially unchanged

Figure 8. Anaerobic digestor for all wet organic waste from city of 90,000 in Finland – approximately 80,000 m3 per year of 10% dry matter.

Chapter 6: Biofuels and rural community economies, jobs, energy self-sufficiency

The harvesting of jatropha seed – or of gathering of other oil-rich seeds as from Croton, Pongamia, Neem etc., as a feedstock for further processing, is proposed as having economic promise for rural communities. It is in this level of scale and approach to value-adding that many NGOs have been working, though with quite mixed success.

On the face of it it seems to have real potential – to gather what is growing freely, and to convert it by simple low-cost processes into a saleable product or to a fuel that can be converted to give other sources of income. However what often seems to happen is that either the alternate fossil-sourced fuel is cheaper, or is seen as less trouble, or the process as described upsets some community status quo. In some cases the problem has simply been one of 'over-promising' followed by 'under-delivery'.

So what is the real potential for this approach of regional biofuels production, and how can the problems experienced to date be reduced or avoided?

Clearly a number of things need to be in place

- Final cost of produced biofuel has to be less than imported fuels
- Production of biofuels or other products should not be at the cost to food production, water availability, ecosystems, or displace populations
- Success of new enterprises should not disrupt the established order, and/or benefits should flow out to the general community
- Technology required must be cost-effective and appropriate in complexity and maintenance requirement
- Income should exceed outgoings in all years
- One or more years of drought should not damage the continuation of the project
- Ideally any new crop should have more than one use (i.e., Moringa and Neem)

Jatropha can fulfil most of these criteria when it is planted as a hedge (so its hedge function is the main benefit and the oil seed function is secondary). The hedge can protect and aid output of vegetables, provide shelter to a house yard, exclude browsing animals from crops, provide bee forage, provide some medicinal uses, and provide some seed harvest. In this planting configuration it does not take up space from food production.

It can also fulfil these criteria when it is planted as a cover crop for other food production, or for a mixed purpose in combination with goats, chickens and honey bees (this option is promoted by Prof. Thomas Sinkala in Zambia).

Another mixed purpose use is for jatropha to be planted to shade or support some cash crop plant like vanilla bean – this option is supported by Vanilla Jatropha in Tanzania.

The development of rural or regional enterprises built around biofuels or other jatropha products generally involves smallholder families and particularly the women in the community. This is the way it has tended to develop in many African countries including Ghana, Zambia, Kenya, Malawi and Tanzania. This needs to be recognised, and any possible problems that might arise in the case of the women in the community achieving some minor success or economic independence need to be anticipated and forestalled.

In the regional communities of many African countries there are already established hedge plantings of jatropha, the harvested seed from which could feed into the flow from plantation jatropha over coming years. Also in these and other areas the women, as well as men and young people from these communities, are likely to become a significant part of the harvesting work force, and it is desirable that the skills for this are already there.

But another question is how the development of a regional jatropha oil industry can help these regional communities become less reliant on imported fossil energy, gain better access to more reliable electricity supplies, develop small scale enterprises and reduce regional deforestation. The use of jatropha pressed seedcake for biogas production, or for compression into briquettes for use as a fuel to substitute for firewood, are both possible and cost-competitive options. Another possibility is to use the seed seconds, husks, prunings or diseased trees to be a feedstock for gasification on small or large scale to produce electricity.

Clearly these options are possible for local or regional energy production. So any overall project strategy needs to look at the way regional communities will fit into a national jatropha oil production industry, so that the outcomes are generally only as positive impacts on regional economies as well as on smallholder and family incomes and health.

The issues of reversing deforestation and having some impact on desert encroachment may be issues that are greater in some regions than others. But there is clearly scope for real progress in this for this in a number of regions of Africa, and in reality this may provide as great an economic benefit for a country over time as the production of jatropha oil for conversion to transport fuels.

Chapter 7: Jatropha seedcake as fuel (Broader issues of deforestation and desertification)

Many countries in Africa and particularly those within the Sahel region, have a high use of biomass for **Deforestation rate.**

Many countries in Africa and particularly those within the Sahel region, have a high use of biomass for energy. Some reports put biomass as providing up to 90% or more primary energy in countries including Mali, Tanzania and Ethiopia. This use principally of wood and charcoal for cooking and industry is now resulting in an unsustainable rate of deforestation or forest degradation. Many African countries rate high on a world-wide scale for their rate of deforestation. In practice this means that the present forest cover is under intense pressure that increases year by year. A forestry report for Sudan estimates that to stabilise this rate of deforestation will require the planting of about 1 million ha of forest a year. While this might be at the high end many other countries are also at risk of losing much of this forest precious asset.

Use of wood and charcoal

The use of wood for fuel in African countries has been the subject of a number of recent reports. While use of wood has declined significantly in the major urban centres of many countries due to availability of LPG, demand is still strong for firewood for the relatively inefficient firing of bricks using a traditional kiln design. This is despite the fact that firing in a more efficient design results in making better quality bricks more cheaply.

Production of charcoal is mainly to sell into its demand for domestic use and for market tea stalls and small food stands. Even at best the charcoal produced is less than 50% of the dry weight of the wood. Its manufacture is a very energy-inefficient process. Much of the charcoal comes from land clearing for rainfed agriculture, or is sourced without license from remaining forest stands. Wood and charcoal are being sourced at greater distances from the final point of use, and in some countries with extensive deforestation this is now up to many hundreds of kilometers

Desertification

In the Sahel countries and in some countries of eastern and southern Africa deforestation is seen to be closely linked with encroachment of desert as temperatures rise and average rainfalls fall. In some countries bordering the Sahara the boundary between open savannah grassland and bare and windblown desert is moving at many kilometers per year. Obviously the combination of deforestation and desertification is a situation that needs to be approached from a number of directions at once to give the best chance of success.

These include:-

- Improve access to LPG and/or compressed natural gas (CNG) for the major users of wood and charcoal
- Develop more effective policies that drive replanting at community, regional and state government level
- Promote species and planting systems that make reforestation more cost-effective and successful
- Audit other sustainably available forms of biomass
- Develop policies that promote the technologies for utilising these
- Reduce forest clearing and unlicensed charcoal making
- Adequately protect existing forest stands, including browsing of natural regrowth

Audit of sustainable biomass

Within the audit of sustainably produced biomass the residues of crop production of all sorts will figure. Some major residues include sugar cane bagasse and harvest trash, cotton stalk and ginning residues (short fibre and seed husk), cereal straw and processing residues. In addition there are the biomass fractions that might not be immediately considered – such as the weeds on land and in water, including mesquite and water hyacinth. Among this audit the potentially very large volumes of jatropha seedcake due to large scale jatropha oil production will be a potential energy source to substitute for wood.

The most cost-competitive sources of alternative biomass will be those where the biomass form that is suited to densification for use as a fuel is already gathered. The best of these will include ones where the energy value per tonne is high, where densification processes are straight-forward and effective, and where the combustion of the biomass in its densified form can be done within existing systems – or systems requiring little modification.

Seedcake as a fuel for combined heat and power (CHP) production

Other than for biogas production (and from this the production of electricity and heat) the seedcake's alternative uses, if produced in scale from seed harvested from large areas of jatropha planting, are as a fertiliser or as a pelleted or briquetted fuel. In any event if a country is to produce enough biodiesel from jatropha to replace even 5% of its diesel fuel (assuming (as in Sudan) total diesel use of about 3 million tonnes, so 5% is about 150,000 tonne of biodiesel) seedcake volumes produced will be very large. Production of the necessary volume of oil will require up to 625,000 tonnes of jatropha seed, and so up to 437,000 tonnes of seedcake will be produced as a residue. In this form it has an energy value of 5 MWh/tonne, and could be used as a fuel in smaller or larger energy plants, including in combined heat and power plants.

In total the 437,000 tonnes of seedcake has an approximate energy value of 2,185 gigawatt-hours (GWhr), and if used to fuel efficient combined heat and power plants could produce about 87 MW of electricity annually (assuming about 5000 tonne to produce a MW-e). These CHP plants could be of any size from 5 MW-e output and up, though normally economics of scale works in favour of plants of over 20 MW-e capacity (and with a plant of this capacity requiring about 100,000 t/yr of seedcake).

Chapter 8: Alternate biofuels with potential

Where a country has a large agricultural sector and potential for large irrigation projects, it has the luxury of Where a country has a large agricultural sector and potential for large irrigation projects, it has the luxury of being able to develop a number of different biofuel production technologies. In addition to jatropha-to-biodiesel these include

- Molasses to ethanol
- Sugar or starch crops to ethanol (including sweet sorghum)
- Lignocellulosic residues (straw) to ethanol
- Flash pyrolysis of lignocellulosic material to bio-oil with conventional refining to drop-in gasoline, diesel or aviation fuels
- Synthetic diesel from gasified agricultural and municipal residues
- Biogas from harvested water hyacinth and other putrescible or green material
- Micro-algae oil to biodiesel

Several of these options should be seriously explored. If there is an existing sugar industry the most cost-effective option among these is the production of ethanol from molasses in an expanded sugar industry (sweet sorghum is mentioned separately as it can produce a similar amount of sugars per ha as sugar cane but is said to require less water).

While the economics of most of the others may not be immediately attractive the technologies for these other processes are into the pilot stage elsewhere. Examples of these include the production of ethanol from straw, stalk, cane trash and other crop residues. This process currently requires large volumes of feedstock (200,000 tonnes plus at any site) and a high capital cost of plant. On the other hand the output from the intermediate stage of fermenting the hydrolysed feedstock can go into a standard distillation plant for the purification process.

Similarly, the bio-oil product from the flash pyrolysis of ligno-cellulosic material can possibly then be sent to be further refined in an oil refinery with necessary modification to deal with the qualities of the oil.

The gasification of lignocellulosic material can be at any scale from about 10 kW-e upwards. Indian-designed and made systems could utilise this technology for production of electricity from a feedstock of jatropha prunings, while another design can utilise the husks of rice or other cereal seed.

However on a larger scale the product of gasification of the feedstock in an oxygen starved atmosphere is cleaned and then reformed to give a range of long chain hydrocarbons depending on the catalysts used. An alternative technical approach in being trialled in a large scale pilot venture in the USA is to feed this cleaned and cooled synthesis gas to clostridium bacteria which then produce butanol – an energy dense alternative to gasoline.

The use of green wastes, water hyacinth, urban sewage and food wastes to produce biogas uses very mature technology. While biogas is essentially natural gas diluted with about 40% CO_2, it can be upgraded to be pure methane which can then be a feedstock for various biochemical processes, including conversion to gasoline or other fuels.

The message of this chapter is that work is proceeding on all options for production of a wide range of biofuels, as it is seen as an area both of great need in the near future, but also as an area of technology that will pay off handsomely for the organisations that develop the best approaches.

Figure 9. An Indian-made 10 kW-e gasifier, designed to run on woody residues or material, including dry jungle vine

Figure 10. The small machine for cutting the lengths of woody weeds or jungle vine, and the cut product ready for fuelling the gasifier

Chapter 9: Government policies and industry support measures

Largely due to concerns about exhaustion of crude oil reserves, and because of concerns about greenhouse gas emissions and global warming, the production of biofuels has jumped from about 16 billion litres in 2000 to about 100 billion litres in in 2010 (IEA Biofuels Roadmap). This trend is expected to continue, and the main source of biofuels will in the short term continue to be USA and Brazil, with the medium term supply increasingly coming from the equatorial countries best suited for fast growth of sugar cane, sweet sorghum and woody biomass.

There are obviously different drivers for different countries to push the production and larger scale use of biofuels. These can be summarised as

- Greater national resource security and a buffering from price volatility, and proofing of the economy against eventual decline in supply
- Less money spent on imports of fossil fuels (but retained in national industry and generating jobs onshore)
- Stimulus of regional and rural economies
- Stimulus of technologies and skill development
- Export of surplus product (and possibly of skills and technology)
- Stimulus of synergistic industries, and biorefineries and cleantech clusters
- Reduction of national GHG emissions, and compliance with renewable energy or emissions targets or binding national commitments

To this point (2012) the main country and regional groupings where biofuels are in significant production and use are those where they are strongly supported by government policies and legislation. These countries and regions that have been leaders in the development of biofuels production and use sectors and have made it work include the EU countries (particularly the EU-15), the USA, Canada, and Brazil.

Some countries outside this leading group that have now adopted ambitious targets or which are commencing large-scale biofuels production include India, China, Argentina, Indonesia, Malaysia, the Philippines and Venezuela. A number of smaller countries finding themselves increasingly exposed to price rises for imported fossil fuels have also developed strategies and legislation for biofuels production and use include countries with existing cane sugar industries such as Jamaica, the Dominican Republic, and Costa Rica.

Increasingly the R&D focus is switching to 'second and third generation biofuels'. These include cellulosic ethanol from straw or wood residues, synthetic natural gas or liquid transport fuels from ligno-cellulosic residues, and fuels derived from micro or macro algae. Leaders in these technologies include Finland, Sweden, Canada, USA, Italy and China. Presently these technologies are only at the beginning of being considered commercial processes, and they generally require either very high capital investment, or very large volumes of feedstock (in the order of 0.5-1 million tonnes per site), and usually both.

The countries in Africa that have introduced legislated mandates for biofuels or have targets for blending by 2015 include Zambia (E5, B10) and Mozambique (E10, B5). Other counties with experience in biofuel production or that have previously had some target include Nigeria (E10), Kenya (E10), Malawi and Zimbabwe.

It is the case that while these countries are large importers of fossil transport fuels and spend a significant fraction of their national income on this, they also tend to subsidise the cost of this to the transport sector and private users. This immediately makes it difficult if not impossible to develop a viable biofuels industry. Transport biofuels are generally more costly than fossil-sourced transport fuels to produce, though the Brazil has demonstrated that fuel-grade ethanol produced from sugar cane can be cost-competitive with gasoline.

The situation in many developing countries in early 2013 is that subsidies on gasoline and diesel fuel make them among the cheaper countries for purchasers of these fuels, even after removal of some subsidy over the last decade has meant that pump prices are greater than what they previously were. The real cost of production in 2012 is said to be at US$0.65-0.70 per litre. Prices in Europe range between $2.00 and $2.60/litre for both types of fuel. Even in the US with its low prices by world standards, cost at the pump of both gasoline and diesel are higher than those in some African countries.

So the question is: *how can a country develop an industry producing biofuels at large scale (5-10% at least of the current volumes of petrol and diesel used) in the situation where the existing fuels are priced well below the real biofuel production costs?*

Experience shows that most of the following things must be in place for a successful introduction of biofuels.

(Note: not all of the following are required, as some are complementary and some may be part of a preferred larger regional strategy)

1. legislation should be in place mandating a set blending ratio (usually 5-10%)
2. subsidies on fuel should be replaced with more effective measures, so that the country can be more in line with trading partners but poor citizens or rural populations not be disadvantaged economically
3. distribution and storage issues need to be resolved to maintain adequate supply and high quality
4. quality and blending ratio of fuels needs to be constantly monitored by a competent testing authority
5. opportunity for corruption of defrauding the system need to be identified in advance and neutralised
6. introduction of incentives for vehicles able to run on higher proportions of biofuel need to be considered
7. issues of excise or tax need to be resolved so that the biofuel is able to compete in price
8. the possibility of using excise revenue raised on fossil fuel to cross-subsidise biofuels
9. the industry – distributors, refiners and major users - must be supportive and part of the process from the beginning and not financially negative affected
10. neighbouring countries need to be encouraged to develop common polices on pricing and blending to prevent cross border smuggling and to allow transport vehicles to run between countries with no fuel grade or quality issues.

Chapter 10: Sustainability

It is appropriate that the topic of sustainability has a chapter of its own, as each part of the production, processing, and use of biodiesel from jatropha has to be looked at on the basis of its sustainability. The sustainability of the overall large scale production of jatropha oil is important, not only because of its positive or negative impacts within the country producing it, but also because being able to qualify for a certification of sustainability means that crude jatropha oil can be sold into the international market to the many buyers seeking a large, reliable and certified-sustainable source of supply.

International criteria of sustainability are laid down by a number of organisations. One principal organisation is the Roundtable for Sustainable Biofuels. This body has a website (www.rsb.org) with information in a number of languages detailing the criteria on which the sustainability of production of biofuels is assessed. These criteria are in line with the criteria specified by the EU for biofuels able to be imported into the EU. The criteria split into three groups: those relating to land use change, those relating to greenhouse gas (GHG) emissions, and the criteria relating to issues of human rights and international law.

To take these groups one at a time. The criteria relating to land use change look at the pre-conversion land use for any site to be used in production of biofuels. Obviously clearing of any dense biodiverse forest with intact ecosystems, or drainage of peat swamps, for planting of biofuels crops will mean it is most unlikely that the product from those crops can be certified as sustainably produced. This is a major problem with the massive plantings of oil palm in many countries. By contrast biofuels produced from crops on degraded farmland that had been cleared in the distant past are likely to be able to qualify as sustainably produced, provided other things about the production process are rated positively under the sustainability criteria.

One of these 'other things' just referred to are the greenhouse gas (GHG) emissions given off by the production process. To produce a low-yielding oil seed crop by use of great expenditure of fossil fuel for cultivating, sowing, harvest, transport and processing may require a much or more fossil energy input (and hence the associated measurable GHG emissions) than the amount of fuel energy in the final volume of produced biofuel at the point of use. This may generally be the case with biodiesel from annual oil seed crops, or for ethanol produced from annual crops like wheat or sugar beet (a counter-balancing figure in this case needs to be the amount and food value of by-products created).

Other criteria covered under 'other things' in the paragraph above include the human rights issues. This covers issues like displacement of indigenous populations (another problem with some country's planting of oil palm), or of rural populations, or of exploitation of children or other workers. 'Exploitation' may cover use of underage children, or enforced labour situation or gross under payment, or forced labour for very long working days and without days off.

In some situations a crude assessment of sustainability can be by comparison to how things are presently done; with use of petroleum-derived fuels for transport and electricity production, LPG for cooking, and wood-derived fuels for some cooking, brick making and baking. Or it can be on an assessment of the real or forecast positive and negative impacts of a large jatropha plantation estate on the environment, surface or subterranean water supplies, livelihoods, habitats or ecosystems of a region.

The term 'sustainability' can be used by different people, departments or businesses to mean many different things. In this chapter and in the context of a large jatropha oil production enterprise unless stated otherwise it refers to the environmental sustainability - the impacts on health and well-being of the ecosystems of plants and animals, and of existing human populations, within the region, and to identify if there are any seriously negative aspects of some practices that need to be modified or avoided.

An example of this might be something as obvious as the over-extraction of sub-artesian water that existing stockherders or horticultural/agricultural managers or communities presently rely on. Or the pollution of these artesian waters with non-biodegradable or problematic substances with long term health impacts. Or it might be something less obvious like the impact that planting a large monoculture of some plant like jatropha will have on insect, bird or animal populations and on the existing human activities in the region.

It could also relate to the seemingly positive impacts of establishment of a series of strategically placed irrigated jatropha plantings and surrounding tall shelter trees in a region in threat of encroachment by desert. The core of jatropha plantings could be used as a source of income and labour for the larger project of planting and other anti-desertification work.

Another aspect of the development of such large and labour intensive plantations is the dramatic increase in truck movements that will result as an annual necessity to move labour, materials and harvested product. The amounts of diesel fuel used for this, as well as for harvesting machinery or irrigation pumps, needs to be entered into any equation of GHG balances for the overall project. It is possible that this fuel use will total as much as 5-10% of the biofuel produced annually for each site.

Sustainability, as in several of the above examples, can be on the positive side also. The seedcake produced from the jatropha seed pressing can be used instead of firewood, and so reduce local deforestation. It can be used as the feedstock for biogas production, and so reduce transport and use of diesel in the generation of electricity for the regional towns or cities. And the residue from the biogas production or the ash from the use of seedcake in brick kilns or energy cogeneration plants can be used back on the production site, and so reduce need for imported synthetic fertiliser.

Other meanings can be given for sustainability, pertaining to society and the economy, that can also apply here, where production of biodiesel from jatropha can reduce national need for import of fossil fuels, with all their attendant shipping and refining cost. Labour needs for picking or other aspects of jatropha site management can help make regional centres more prosperous. The existence of a large jatropha industry can allow smallholders to produce and sell into this larger system for cash income, so providing a more robust regional economy, and a second line of income to small holder families.

Overall for a country a 'good' rating for sustainable biodiesel production requires:-

- The planting of large areas of jatropha be on sites that are not currently used and not forested. This would appear likely to mean a low land-use-change impact.
- Jatropha oil production should be classed as positive for the greenhouse gas emission balance, provided yields are relatively high and emissions involved with management, harvest, transport and processing are relatively low.
- The establishment of these large jatropha plantings should not significantly displace any existing practices like livestock herding or dryland agriculture then it should rank as positive or at least neutral for these criteria.
- The use of irrigation water should not lower the supply from aquifers, result in salinity problems or result in competition with food crops for available irrigation supplies, any criteria related to water use should be neutral.
- People employed in the jatropha estate should be paid the going wage rate for their type of work and any employment of school-age children regarded as acceptable under any labour criteria within 'sustainability'.

The sustainability rating and certification of oil or biodiesel produced from jatropha would be likely to be enhanced by:

- Demonstration of positive benefits to the ecology of the regions
- Demonstration of positive carbon sequestration by the growing jatropha plants, and of any possible displacement of use of wood or charcoal (and so reduction in deforestation) by pressed jatropha seedcake
- The demonstration of the impact on desertification by the combined jatropha and tall shelter trees in strategically placed plantings in the northern regions
- The reduction in use of fossil fuels through a well-organised introduction of jatropha biodiesel blended with fossil diesel, or of use of biodiesel for rural and regional electricity generation
- Any positive impacts of smallholder jatropha seed production and other positive social or economic impacts for regional economies and communities
- Any positive impact on regional climates or on local microclimates would be an additional benefit that should be quantified and detailed
- Any positive trend in overall national GHG emissions

One last note on sustainability. Planting of vast areas of a jatropha monoculture comes with inherent risks. These

- include negative impact on labour pools in regional areas,
- negative impacts on water availability for food crops or over-use of water from aquifers, meaning inadequate long-term irrigation flows
- the possibility of insect pests or fungal disease impacting the viability of whole plantations
- yields being low due to lack of development of management best practice, or not using best available genetics.

While these issues may not make the jatropha oil or biodiesel fail the criteria of environmental sustainability they will certainly impact on economic sustainability or social sustainability of the whole venture.

Figure 11. Clearing of forest or woodland for jatropha plantings would make biofuels from jatropha far less environmentally sustainable

Figure 12. Negative impact by jatropha plantings on recharge of aquifers or by depletion of sub-artesian reserves for irrigation would reduce any claim of jatropha oil to be classed or sold as being 'sustainably produced'

Sudan's Biofuels Roadmap

(Note – this section may be used as an example of one approach for development of a Biofuels Industry Roadmap but should be modified or adapted for any other country)

Introduction

Sudan is one of the largest countries in Africa with a total area of 1,882,000 sq km, and a population of about 33.5 million (growth rate of 2.84% per year). Sudan's energy demand has significantly grown through the past 20 years. Oil consumption has rapidly increased as a result of country economic growth. While oil is the main source of energy, the transportation sector is the main consumer for the refined fuel products, consuming about 61% from the total crude oil volume presently produced. The major fuel form used is diesel which represents 50% of the total fuel consumption, whilst gasoline and jet A1 represent 23% (see figure below). The secession of South Sudan in 2011 with most of the productive oil fields has left Sudan with sharply reduced oil volumes to export (the main source of export income). Petroleum product subsidies accounted for about ¾ of tax revenues in 2011 and have been on the rise as a consequence of this secession and the related loss of oil production.

Though Sudan is facing a suddenly change in the outlook for its fuel sector following the separation of the south there has not been any detailed biofuels policy developed. Therefore an explicit, transparent, and integrated roadmap of biofuel development should be devised to guide and promote the development of biofuels production and availability in Sudan. The Aeronautical Research Centre in Sudan initiated the development of a National Roadmap for Sudan's biofuel production, based on using jatropha oil as the main feedstock. This Roadmap will investigate the resources related to industrial scale production, detail the technology approaches of all stages of development, and schedule planning policies and incentives to industry within a specific timeline. This roadmap also will promote cooperation and development activities with local government, the public and smallholders. This latter part will focus on establishment of pilot jatropha oil production projects in rural areas to demonstrate greater energy self-sufficiency and the benefits of this to rural economies, as well as better utilization of available forms of biomass for energy production. This roadmap should contribute to national energy security and reduce Sudan's GHG emissions contributing to global warming and climate change. It should provide specific detail for agricultural production of biofuels feedstocks and for infrastructure optimization solutions. An effective biofuels policy has the potential to reduce the problems presently facing agriculture, rural areas and farmers. In a scenario of global warming lifting average temperature by over 2 degrees C agriculture and all other aspects of life in Sudan would be significantly negatively affected.

The objectives of the Roadmap development can be summarized as follows:

1. To assess the economic feasibility of a biodiesel sector based on domestically produced jatropha oil (possibly in some combination with other non-fossil sources yielding a suitable quality of oil or fats on a genuinely sustainable basis and in adequate quantity).

2. To assess the necessary legislation and other policy structures required for long term viability of production of biofuel in Sudan.
3. To do a study and forecast covering within specific timeline on:
   - Sudan's transport fuel requirements – including aviation fuels,
   - Fossil fuels availability within the world market, and likely pricing and demand trends,
   - The costs to Sudan of over-reliance on fossil fuels in a 'business as usual' scenario,
   - The broader benefits of some significant degree of conversion to use of domestically produced biofuels (particularly biodiesel and bioethanol), including social, environmental and economic factors.
4. To identify the key regions, land availability, and agronomic, economic and social issues involved with development of a large domestic production of *Jatropha curcas* and other possible biofuel feedstocks.
5. To identify the requirement for processing plants, refining plants, distribution networks, blending options, quality control (and certification or standards labelling), licensing and taxation (or exemption from government excise duties, or equivalent subsidy to that applying to fossil fuels), pricing and subsidy forecasts, government oversight personnel, monitoring and testing facilities, and the many other issues of introducing this new biofuel production and sales system.
6. To provide examples from other countries of biofuel introduction at a national level that have failed for whatever reason, and of ones that have succeeded; and analyse and identify the reasons for success or failure.
7. To draw attention to better utilization of available forms of biomass (including biowastes) for energy production.

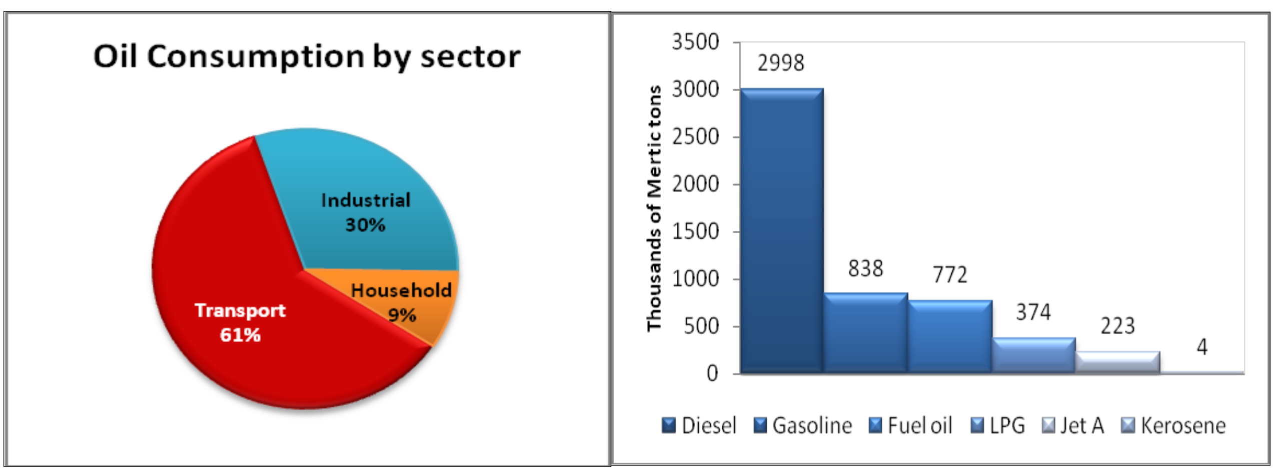

Figure 13. Fuel Product Consumption in Sudan, 2012 (Source: IMF Country Report No. 12/299)

The Sudan Biofuels Roadmap being developed within the context of the following:

- a fall in available crude oil extraction for Sudan to about equal the domestic demand of 115,000 barrels/day (and the recent loss of export volumes that had earned a large share of export income, and consequent impact on currency exchange rates and on Sudan's international debt)

- the likelihood of increasing price volatility and world shortages of better quality crude oil
- a high population growth rate (about 2.84% pa)
- One of the world's highest deforestation rates (over 2.5%)
- increasing desertification (edge of desert supposedly moving south at 8km/yr), rising average temperatures, and falling average rainfall – all of which impact Sudan's food production from livestock and rainfed agriculture, and ability to grow some crops
- a significant subsidy on retail cost of diesel and other petroleum products. This has just been halved and may be further reduced in the near term, but is still significant.
- an appreciation across the world's national governments, and by the UN and EC, of the urgency to reverse deforestation and reduce global greenhouse gas emissions
- new technologies for production of energy, including transport fuels, from biomass including cellulosic residues (also from feedstocks like water hyacinth and microalgae)
- a international commitment of funding and R&D into major sequestration of carbon, and conversion to use of renewable energy, and greater energy efficiency.

Some other key issues are:

- How biofuel production of this scale will be reliably profitable to investors (of time, money and land), and how the set-up phase will be properly managed from pilot production and through expansion?

- What legislation needs to be in place to assist a biofuels sector to fit in with the far larger and possibly aggressively competitive fossil fuels sector?
- What happens with unforseen issues due to cross-border pricing of fuels and particularly in relation to any subsidy in balance on either side of national borders (i.e., if Sudanese biodiesel is to be sold at prices that will result in its flow to Egypt or Kenya for instance)?
- Who will be opposed to introduction of significant domestic biofuels production
- Which sector will be used to support initial production of biodiesel – city public transport, the army, local government…?
- Timeline available that the development of a biofuels industry should fit within.
- Identification of foreseeable risks – significant climate change, fluctuations in international crude oil prices, discovery of further major domestic natural gas reserves, significantly higher foreign prices available for clean jatropha oil.

- The sourcing of the feedstock and how to ensure that flow of feedstock volumes is adequate and certain – and how to protect the interests and investment of the growers? What part does the government play? What is the availability of CDM or other 'clean energy' funding.

An overview of Sudan's situation regarding biofuels development

Sudan, while a 'developing' country, has many obvious positive strengths that have the potential if harnessed for providing great economic benefit. It also has some negatives that separately or together will handicap development of a biofuels industry – though in some cases regional biofuels production may reverse or reduce these negatives.

The positives for Sudan

Water: Sudan has access to the flow of the Nile River through the length of the country from Khartoum to the north, with the White and Blue Nile south of Khartoum each supplying water to very large irrigation schemes. Several major hydroelectric dams as well as oil, gas and biomass-fired plants supply about 2000 MW of electricity to Sudan's main cities and industries as well as into some of the irrigation schemes. The rights of Sudan to draw on this annual flow for irrigation are presumed to not be fully exploited (over 18 billion m3).

Sunlight: Sudan has a very high solar radiation incidence, and as well as harnessing this both for solar hot water for households and industry and solar photo-voltaic electricity supply for remote communities, Sudan could develop the technology for larger solar concentrating electricity systems for regional urban centres. Contribution to capital costs for development of this could come from the European Community members, either as offset against their own GHG emissions or for the rights to draw some electricity from this. On the basis of this solar potential Sudan could be a leader or partner in technical developments in solar technology.

Culture and history: Sudan has sites of world significance in terms of history and archeology – notable among these are the pyramids of the Kushite kings at Meroe and at other sites of this and other eras of its history and pre-history. Also the biology and scenery of long stretches of the Nile are attractive for tourism, and the coast of the Red Sea and the mountainous border regions with Eritrea and Ethiopia are also potentially of interest to international tourism. Similarly, the cultural and ethnic diversity of Sudan means locally-based tourism could be a significant earner of international income.

Petroleum: The oil and gas fields in the centre and south of Sudan are not fully explored or exploited, and the significant reserves of natural gas have not been exploited and in some instances natural gas produced as part of oil production is flared. Natural gas elsewhere is used as a vehicle fuel, as a source of cooking and industrial heat, and for electricity production. In Sudan till now LPG provides much of these demands. An additional use of natural gas is as a feedstock for production of diesel, petrol and of petro-chemicals including plastics and dyes.

Agri-biomass: Sudan's extensive irrigation and rainfed agriculture produces many tens of millions of tonnes of residues and by-product that could be feedstock for energy generation or used as an alternative fuel for industry including brick making.

Land tenure system & Educated workforce: Sudan has a land tenure system that provides security and opportunity to invest in industries and technologies that offer adequate returns when risk is considered. Educational and literacy measures are good and tertiary-trained graduates are available for working in and managing new industries and sectors. At the same time labour costs are relatively low.

Some negatives or handicaps

Supply of services to regions: While much of Sudan's population in the Nile Basin and south-eastern states has access to the national grid and bottled LPG , much of the rest of the country in the north and west has relatively poor infrastructure, unreliable energy supply and limits in other services.

Drought-prone: The low and variable rainfall and high average temperatures mean many agricultural crops are not suited to rainfed sites. The trend over time is for average rainfall at any point to reduce and average temperatures to increase.

Desertification: A large and expanding part of Sudan's northern half is predominantly desert, with the boundaries of this moving southward.

Deforestation: High use of wood and charcoal for domestic and industrial heat energy means deforestation is out of control, with supply being transported from as far as 1000 km to main urban centres. Major development of alternate affordable fuel supply will be required to reverse this. Major reforestation projects are also required.

It is in the context of this catalogue of positives and negatives in Sudan that the potential of development of an industrial scale biofuels supply needs to be assessed. This biofuels development actually fits within the development of bioenergy in Sudan - covering use of biomass of all types, including forest and agricultural residues and biowastes from industry and urban centres, to produce energy. This energy produced may be in the form of heat, electricity, liquid and gaseous transport fuels, or gas or liquid fuels for use in industry and households.

In reality biomass makes up the largest source of Sudan's primary energy, according to recent reports providing about 60% of total energy needs. This is mostly as wood/charcoal fuels for heating and cooking, but also as agricultural residues for electricity production. However this use of biomass is only sustainable in some industries. For other uses it is anything but sustainable.

However, this Sudan Biofuels Roadmap will be limited to identifying and examining the alternative liquid transport fuels that can be produced in Sudan that could be used either pure or as a blend, to fuel existing types of cars and trucks. It will include comment on the logistics, economics, risks, necessary scale, and case studies from elsewhere, necessary policies, and other aspects. Because of the initial directions of the development of the Roadmap it will focus particularly on the potential for oil produced from *Jatropha curcas* to be cost-competitively used to make biodiesel.

The alternative feedstocks and technologies for production of liquid transport biofuels

(Ranked 1-5 on economics, with 1 being most cost-competitive – Note-this scoring is very approximate, and technologies and economics are in in a state of change)

*Ethanol from molasses (from sugar cane – a semi-perennial) (1)

*Ethanol from annual crops (wheat, sweet sorghum) (3)

*Ethanol from food residues high in sugar/starch and industrial milling residues (1)

Ethanol via enzymatic/acid breakdown of ligno-cellulosic residues and by-products (4-5)

*Biodiesel from used cooking oil or animal fats (1)

*Biodiesel from vegetable oils (annual crops) including rapeseed and soybean (3)

Biodiesel from vegetable oils (tree crops) including jatropha, pongamia (4-5)

Hydrotreated (hydrogenated) vegetable oils to biodiesel (3-4)

Synthetic diesel via gasification and reforming (using lignocellulosic residues or MSW) (4-5)

It needs to be appreciated that of this list only some are currently commercial. The underlined processes or feedstocks above are the most cost-effective and seen as the most sustainable of these

(Other possible biofuels include methanol, dimethylether (DME), butanol)

Bio-ethanol

Over 80% of the world's currently produced biofuel is ethanol (86.1 billion litres in 2011), with the best economics for production of this being from sugar cane and particularly from the molasses by-product. The USA and Brazil are leaders internationally in this and currently produce ethanol cost-competitively with petrol, and both export to many countries. This shows the potential for ethanol as a biofuel. It can be used for heavy vehicles and, for example, fuels many Stockholm city buses. It has been shown that when mixed with 5% of an added diesel enhancer pure ethanol can be a technically feasible fuel for diesel engines.

In Africa, Kenya, Ethiopia, Mozambique, Malawi, Zimbabwe and Zambia have all entered into fuel-grade ethanol production since 1980, though for some it has not continued. In all of these countries government legislation required some obligatory ethanol/petrol blend – usually 10% ethanol. However the costs of producing ethanol in older plant or lack of a coherent properly-thought through set of guiding policies can lead to a failure. Obviously scale or production, standards, distribution systems, quality of storage, and retail pricing, are critical in all this.

Bio-diesel

Nearly 20% of the world's biofuel is as biodiesel (21.4 billion litres in 2011) and almost all of this is the type produced by taking a vegetable oil or animal fat and using a process called transesterification to convert this into a fuel with many similarities to fossil diesel. This form of biodiesel is often called fatty acid methy ester or FAME. It may also be called after the feedstock – so rapeseed methyl ester RME.

The most important of these characteristics that biodiesel must have are similarities in viscosity, lubricity, energy density, cloud point and flash point. While better quality 'drop-in' non-fossil diesel substitutes can be made by other processes, a major advantage of transesterification is that it can be done quite cost-effectively at relatively small scale, using affordable equipment and without need for high pressures or temperatures.

However there are several reasons why production of biodiesel lags behind that of ethanol. The main one is that of cost of the feedstock. In most cases this is because the feedstock is an edible vegetable oil in strong enough demand on world markets that its price is relatively high and stable, and so this price means that biodiesel is almost always more expensive than the fossil-sourced diesel. In the regions where biodiesel is used as a mandated blend in diesel (usually as B5 or B10 – i.e., as a 5% or 10% mix) it is both because of the mandated blending percentage and because the cost of the fossil diesel is elevated far above cost of production because of a carbon tax or excise taxes as in most of the EU countries.

An associated reason for lower production of biodiesel is the simple difficulty of getting a high yield of vegetable oils per ha. While palm oil yield is the highest at about 4 tonne/ha, most vegetable oil yields are under 1 tonne/ha. In general these crops require good arable soils, temperate climate and relatively high rainfall. It is this situation that explains the strong interest in oil-producing perennial or tree species like Jatropha, Castor, Pongamia, Croton and Neem, among others. Among these jatropha has received most attention and investment recently due to its perceived abilities to produce well in marginal sites with low and variable rainfall. With optimal management on good sites jatropha may be able to produce the next highest yields (after the oil palm) at over 1.5 tonnes of oil per ha.

However, large-scale plantings of jatropha in many countries in the period 2000 - 2010 have culminated in failures of many schemes and losses of money by governments and hopeful investors. Almost no scheme managed to produce anything like the forecast yields, and large numbers of smallholders who were persuaded to invest time, land and money found that in the end they would have been far better off to continue to grow millet, potatoes, sunflower, or whatever their normal cash crop was. This has been the case in Tanzania, the Philippines, Myanmar, Zambia, Ethiopia, India and elsewhere. Of the over 900,000 ha known to have been planted to jatropha between 2000 and 2010 only occasional plantings have consistently produced yields of over 1.5 tonne of seed per ha from year 5 on. And these are usually in areas where more value of product would have been produced by other crops.

The potential of jatropha

It is within the context of this background that we looked at the potential for jatropha in Sudan as part of the Sudan Biofuels Roadmap. Over the last ten years work has been going on in many places on improving the genetics of *Jatropha curcas* which till the world-wide work of the last 10-15 years has essentially been an unselected 'wild' plant. This genetics work is focused on several main characteristics: the development of strains producing non-toxic seeds, the development of much higher yielding strains, development of strains with more even ripening of fruit, and the development of strains with more reliable yield in lower rainfall environments.

In addition, research and development has produced household affordable cook stoves that can work well when fuelled by jatropha seed or pelleted seedcake, cost-effective systems for pelleting or briquetting seedcake, small-scale equipment suited to rural cooperatives for expelling oil, and affordable engines/gensets that will run on pure vegetable oil.

To date while there have been large-scale plantings in many countries these are often an aggregation of many small plantings that have not been optimally managed or sited. Clearly to be able to get the necessary yields at a net price per unit of oil that will give a return on investment the whole approach has to be reviewed.

Investors in Sudan can start from the proposition that to be profitable a site needs to produce about 1.5 tonnes of jatropha oil a hectare annually from the age of 5 years and on. At about 30% oil content this requires a yield of 5 tonne of seed/ha. Where plants are at a spacing of 3mx3m this means 1100 plants/ha. To get 5 tonne/ha thus requires a harvest of 4.5 kg per bush. Each fruit usually has 3 seeds and there are up to 1300 dry seeds per kg, so this harvest will require each small tree to have about 1800 fruits. The fruits are only born on the ends of the branches, and assuming a selected jatropha bush will produce about 20 fruits in a cluster on the end of each branch, to get this harvest from one fruiting will require up to 100 branch ends.

In practice it is possible with an adequate watering system and a 'good' site to have three fruitings a year, so in this situation each bush would need only 30 branch ends with this fruiting. But it also means that in an environment with only one fruiting, or even two, that yields will never reach this notional profit point unless the number of branch ends bearing fruit are up around 60 to 90 per bush (for two or one fruiting).

Obviously to get this sort of yield will require intensive early pruning, genetically selected trees, a soil quality and depth and fertilizing regime that maintains yields, and a supply of adequate water of good quality to each jatropha plant's root system at the right times. In addition the site has to be within jatropha's range of required conditions of average maximum summer temperatures and minimum winter temperatures, and have shelter from excessive wind or driven sand. Enough pollinating insects will need to be available at each flowering, and no pest insect or fungal disease can be allowed to affect flowering, fruit development, or plant health in other ways.

Finally, the picking has to be done efficiently – as this process can constitute up to 80% of the variable costs. And the seed, or pressed oil and seedcake, must have a market value that is well in excess of all annual fixed and variable costs (in addition to labour), including interest on investment in land acquisition, seedlings and site establishment, and also on depreciation of capital equipment.

Policy framework:

Note: *This following material is the process advised by the International Energy Agency in its publication (Biofuels for Transport Technology Roadmap) for national development of a commercial biofuels sector. Development of large scale production of biofuels in Sudan or other African countries should take some note of such advice from this leading international organization, particularly as relating to sustainability and any eventual export of biofuels. Note that timelines are dated for European policy and industry development from the issue of this publication. For the case of Sudan these start/finish dates would need to be advanced by about five years. For any other country the time-scale would also need a revision.*

Roadmap actions and milestones

Recommended actions	Date
Create a stable, long-term policy framework for biofuels, to increase investor confidence and allow for the expansion of biofuel production.	*2010-30*
Provide sufficient support (e.g. through grants and loan guarantees) that addresses the high investment risks related to commercial-scale advanced biofuel plants.	*2010-20*
Reduce fossil fuel subsidies and introduce CO_2 emission pricing schemes.	*2010-30*
Introduce mandatory sustainability requirements based on internationally aligned certification schemes.	*2010-20*
Link financial support schemes to the sustainable performance of biofuels.	*2010-30*
Adjust economic incentives over time, as biofuels move towards competitiveness with fossil counterparts.	*long-term*

International Collaboration

Recommended actions	Date
Expand international RD&D collaboration, making best use of national competencies.	*2010-2050*
Enhance exchange of technology and deployment, including best practices for sustainable biofuel production.	*2010-2030*
Enhance efforts to align certification schemes based on commonly agreed sustainability indicators.	*2010-2030*
Increase efforts to align technical standards for biofuels and vehicles to reduce trade barriers and infrastructure compatibility problems.	*2010-2030*

Near-term actions for stakeholders

Stakeholder	*Action items*
National governments	• Provide long-term targets and support policies that stimulate investments in sustainable biofuel production and ensure that advanced biofuels reach commercial production. • Ensure increased and sustained RD&D funding to promote cost and efficiency gains for conventional and advanced biofuels. • Implement sound sustainability criteria for biofuels, based on internationally agreed indicators. • Promote good practices in biofuel production, particularly in feedstock production. • Set minimum GHG reduction targets and integrate the environmental and social performance of biofuels in national support schemes. • Work towards the development of an international market for biofuels by seeking commoditisation of biofuels and elimination of trade barriers. • Progressively eliminate subsidies to fossil fuels, and establish a price for CO_2 emissions. • Consumer countries should offer technical and financial support to producer countries for land-use planning and mapping. • Ensure that biofuel policies are aligned with policies in related sectors, such as agriculture, rural development and energy. • Extend sustainability criteria for biofuels to all biomass products (including food and fibre) to ensure sustainable land use.
Industry	• Establish commercial-scale cellulosic-ethanol, BtL and bio-SG plants by 2015. • Develop and implement credible, independent sustainability certification schemes. • Develop concepts for efficient process integration within a biorefinery approach. • Improve feedstock flexibility of processes to allow a broader range of feedstocks and reduce feedstock competition. • Engage in public-private partnerships to support smallholder qualification and participation in biofuel value chains. • Establish large-scale field trials and vigorously pursue the

Stakeholder	Action items
	development of new, more sustainable feedstocks. • Share demonstration project data more widely to improve public acceptance.
Stakeholder	*Action items*
Universities and other research institutions	• Further improve life-cycle assessment methodology for biofuels, and refine methodology to account for indirect land-use change. • Collaborate with industry on large-scale energy crop field trials. • Improve economic models based on detailed cost-curves for feedstock supply in different regions to improve analysis of bioenergy potentials. • Develop national biofuel RD&D roadmaps to identify critical technology breakthroughs needed for sustainable biofuel production. • Develop systems to monitor and avoid (indirect) land-use change.
Non-governmental organisations	• Monitor progress toward biofuel development and policy milestones and publish results regularly to keep governments and industry on track. • Provide objective information on the potential of sustainable biofuels to mitigate climate change, increase energy security, and provide economic benefits to rural communities.
Intergovernmental organisations and multilateral development agencies	• Work on standardisation of fuel and feedstock quality to enhance trade between countries. • Provide capacity building/training for regulatory frameworks and business models to help developing countries implement sustainable cultivation techniques, feedstock supply and biofuel conversion. • Promote and facilitate a structured dialogue between policy makers and the roundtables that are developing standards for the certification of biofuels or biofuel feedstocks, in order to ensure coherence between regulatory frameworks and standards. • Serve as platforms for research and exchange between different sectors – including government, research institutions and the private sector. • Provide technical support to help developing countries devise and implement certification schemes and biofuel support policies.

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