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COMPETE

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

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2 BACKGROUND

The implementation of alternative energy crops and agro forestry schemes has recently gained large interest worldwide, especially in developing countries in Asia and Latin America. Brazil and Argentina have emerged as global leaders in the development of bioethanol fuel from sugarcane and biodiesel production from soy respectively. In Asia: Indonesia, Malaysia, India, China and others have made tremendous strides in implementing energy crop programmes with sugarcane, oil palm and Jatropha as key energy crops. Invaluable experience has been gained through these programmes and some of the lessons learnt in these regions can be replicated in Africa.

There are few experiences of large scale commercial energy crop and biofuel production and use in Africa. Sugarcane growing is however an exception as the crop is widely grown commercially in a number of African countries. In fact the region has some of the most efficient sugarcane industries in the world. The focus of the sugar industry has, however, been towards fulfilling the sugar/food market with only isolated cases of alcohol production from molasses, a by-product of sugar production. Some experiences in commercial biofuel production and use are limited to countries such as Malawi and Zimbabwe.

Currently there are numerous energy crop and biofuel production initiatives (mainly at pilot scale) in various African countries. Production of biodiesel from plants such as Jatropha curcas has especially been a key focal area of pilot project initiatives and countries such as Mali and Tanzania have demonstrated some success at local level. For biofuels to make a significant impact in African economies, considerable up scaling of such pilot activities is necessary taking into account the lessons learnt in their implementation as well as replicating important examples from other developing countries.

A number of barriers hinder the up scaling of energy crop production and expansion of biofuel production undertakings in Africa. These range from technical barriers and adverse market conditions to capacity problems. Important barrier removal strategies can also be learnt from examining various pilot/demonstration projects as well as successful programmes in other developing countries.

2.1 Objectives

Implementing biomass energy projects in a sustainable and socio-economically acceptable way in developing countries is more problematic than in industrialised nations. Already a lot of experience has been gained with such projects in developed countries and some developing and emerging economies but the lessons learned are not very well disseminated. Generally the conditions in developed countries make it inappropriate to replicate success stories in the developing world, especially in Africa.

This review links energy crop production activities in Africa with successful research and demonstration efforts in energy crops and agro-forestry systems in Latin America and Asia. It highlights lessons learnt from best practices that have the potential for application in Africa as well as the possible implementation challenges in the biofuel value chain from agronomy to markets in the African context. It provides strategic recommendations for implementing best practice through appropriate policies and discusses the socio-economic and environmental impacts of selected approaches.

2.2 Structure of the report

This report has three main parts; the first part is a review of international best practice for Africa based on International Energy Crops and Agro-forestry Experience. The second part outlines key issues for implementation, strategy, and policy frameworks in Africa. The third part reviews the status of biomass gasification and the opportunities for learning from international experiences, especially in India, as well as addressing some aspects of technology transfer. Although this third section is oriented towards the conversion stage and not directly related to energy crops *per se*, this review of biomass gasification has general applicability for agro-industries associated with energy crops, since the implementation of bioenergy systems will inevitably require more efficient conversion systems in order to make energy crops cost-competitive and environmentally compatible. Similarly, technology transfer is a crucial element of almost any feasible bioenergy strategy in Africa (except for South Africa) since their smaller size and/or lower level of industrial development will inevitably require the import, licensing and/or adaptation of technologies, energy crop varieties and management systems.

PART A: REVIEW OF APPLICABLE BEST PRACTICE FOR AFRICA BASED ON INTERNATIONAL ENERGY CROPS AND AGRO-FORESTRY EXPERIENCE

3 INTRODUCTION

The historical development of biofuels has been driven largely by the need to find outlets for surplus agricultural production and help keep farmers on the land. Biofuels begun to be considered as a serious alternative energy resource in the 1970s when prices of crude oil shot up in the wake of supply disruptions in the Middle East. Since then biofuels have been developed in their own right as an alternative source of renewable energy. Brazil offers the best example of a sustained biofuel programme since its PROALCOOL programme was launched in the 1970s. Other countries across the globe have since followed suit and from the turn of the century global production of biofuels has grown phenomenally with the USA and Brazil leading in bioethanol production while mainly Germany and Argentina leading in biodiesel production.

3.1 Biofuels overview

Liquid biofuels include pure plant oil (PPO) or straight vegetable oil (SVO), biodiesel, and bioethanol. Biodiesel and PPO are produced mainly from the so-called lipids (vegetable oils/fats and animal fats) while bioethanol is primarily derived from sugar cane, maize, and other starchy crops. Global production of biofuels consists primarily of bioethanol, followed by biodiesel.

Straight Vegetable Oil/Pure Plant Oil

SVO/PPO can be used in place of petro-diesel to run machinery, including vehicles; however due to technical difficulties (especially high viscosities and presence of impurities such as free fatty acids, phospholipids, sterols, water and odorants) SVO/PPO should be used in most modern diesel vehicle engines only after some technical modifications. Principally, the viscosity of the SVO/PPO must be reduced by preheating it. However, some diesel engines can run on SVO/PPO without modifications.

PPO is obtained from oil-producing plants such as the African palm, groundnuts, cotton seeds, sunflower, canola, or non-edible oils such as jatropha, neem, or balanites. These raw oils, unused or used, can be employed in certain diesel engines, for cooking, or in diesel generators for the production of electricity.

Since the interest in vegetable oil-derived fuels began during the late 1970s, four possible approaches to adapting the fuel to the use of the diesel engine in order to overcome the problem of high viscosity were investigated. These were transesterification, pyrolysis, blending with conventional petroleum-derived diesel fuel, and microemulsification [Knothe *et al.* 2005]. Pyrolysis is the thermal decomposition of a molecule, brought about in the absence of air or oxygen and optionally in the presence of a catalyst. Microemulsification involves the formation of a thermodynamically stable dispersion (colloidal in nature) of two otherwise immiscible liquids in the presence of emulsifiers, usually surfactants. Blending simply involves the mixing of the vegetable oils with light petro-diesel in appropriate proportions in order to attain the desirable viscosity. Transesterification of the plant oils with lower alcohols turned out to be the ideal approach to modifying the plant oils and hence the term biodiesel is now used to denote products obtained through this technology.

Biodiesel

Biodiesel is a mixture of mono-alkyl esters produced by the transesterification of vegetable oils/fats and animal fats (which are triglyceride esters) with alcohols in the presence of a catalyst. It can be used in compression ignition engines with little or no modification. Biodiesel can be blended in any proportion with mineral diesel to create a biodiesel blend or can be used in its neat or pure form. It can be utilised not only as a transport fuel but also for powering some machines for small scale industries and for lighting. Biodiesel can be produced from different feedstocks, such as seed oils (e.g., rapeseed, soybean, jatropha, palm oil, hemp, algae, canola, flax, and mustard), animal fats, and/or waste vegetable oil.

Alcohols

Ethanol, butanol, and methanol are produced principally from energy crops such as sugarcane, maize, beets, yam, or sweet sorghum. Ethanol is the most widely used alcohol, primarily as a fuel for transportation or as a fuel additive. Bioethanol can be produced from a variety of feedstocks, including sugarcane, corn, sugar beet, cassava, sweet sorghum, sunflower, potatoes, hemp, or cotton seeds, or derived from cellulose waste.

3.2 The biofuels industry

The biofuels industry has grown by leaps and bounds from its marginal state in the past decades to a multi-billion-litre production in recent years. Between 2001 and 2006, ethanol production has grown by 22.7% per annum and biodiesel by 43.2% per annum globally [RFA, 2009]. Fuel ethanol production increased by 34% in 2008 to 67 billion litres (See Figure 1). Thus, global fuel ethanol production by 2008 had more than doubled from 30 billion litres in 2004. Fairly stagnant for a number of years, fuel ethanol production in Brazil ramped up dramatically, increasing from 18 billion litres in 2006 to 27 billion litres in 2008. It was for the first time ever that more than half of Brazil's non-diesel vehicle fuel consumption came from ethanol in 2008. Notwithstanding Brazil's achievement, the United States remained the leading ethanol producer, with 34 billion litres produced in 2008. Other countries producing fuel ethanol include Australia, Canada, China, Colombia, Costa Rica, Cuba, the Dominican Republic, France, Germany, India, Jamaica, Malawi, Poland, South Africa, Spain, Sweden, Thailand, and Zambia.

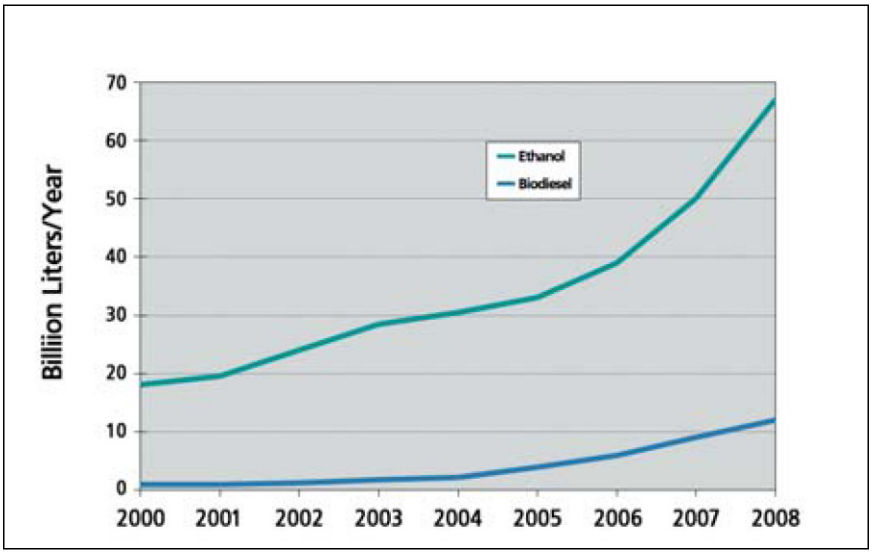

Figure 1: World Production of Ethanol and Biodiesel (million litres)
Source: REN21 [2009]

Biodiesel growth rates have been even more dramatic than ethanol, although absolute production is still much less than ethanol. Biodiesel production increased six fold from 2 billion litres in 2004 to at least 12 billion litres in 2008. (See Figure 1 and Table 1) The EU is responsible for about two-thirds of world biodiesel production, with Germany, France, Italy, and Spain being the top EU producers. By the end of 2008, EU biodiesel production capacity reached 16 billion litres per year. Outside of Europe, top biodiesel producers include the United States, Argentina, Brazil, and Thailand.

The ethanol and biodiesel industries expanded in North America and Latin America, and to a lesser extent in Europe. During 2008, 31 new ethanol refineries came online in the United States, bringing total production capacity to 40 billion litres per year, with additional capacity of 8 billion litres per year under construction. (There were also about 1,900 E85 ethanol refuelling stations in the United States, mostly in the Midwest.) In Brazil, the biofuels industries expanded dramatically during 2007/2008, with over 400 ethanol mills and 60 biodiesel mills operating by the end of 2008. About 15 percent of Brazil's ethanol production was exported in 2008. Argentina became a major biodiesel producer in 2008, with 18 commercial plants in operation, all producing for export; another 16 plants were expected during 2009 to bring capacity to 1.8 billion litres per year. In Europe, more than 200 biodiesel production facilities were operating, and additional ethanol production capacity of over 3 billion litres per year was under construction [REN21, 2009].

Due to the ambitious targets being adopted by many countries worldwide, it is anticipated that worldwide biofuel consumption and trade will grow significantly. For instance, it is estimated that worldwide fuel ethanol consumption would reach more than 500 billion litres per year assuming gasoline displacement by ethanol of 20% globally by 2030 (this assumes that large scale ethanol production from cellulosic materials becomes feasible in short- to medium term) [Walter, *et al*, 2008].

Table 1: Biofuels Production in 2008 (billion litres)

Country	Fuel ethanol	Biodiesel
United States	34	2.0
Brazil	27	1.2
France	1.2	1.6
Germany	0.5	2.2
China	1.9	0.1
Argentina	—	1.2
Canada	0.9	0.1
Spain	0.40	0.3
Thailand	0.3	0.4
Colombia	0.3	0.2
Italy	0.13	0.3
India	0.3	0.02
Sweden	0.14	0.1
Poland	0.12	0.1
United Kingdom	—	0.2
World Total	67	12

Source: REN21 [2009]

Part of the biofuel demand is expected to be met by trade between developed countries and producers in the South. Developing countries have enormous potential to rapidly increase biofuel production given the conducive tropical climate favourable for the production of energy crops. Although Africa still lags behind biofuel production, other developing countries such as Brazil, China, India, Argentina, Thailand and Pakistan have established multimillion dollar biofuel industries and are among the top producing countries. The experience and policies of these countries deserves serious attention as Africa examines its potential for increased biofuel production.

3.3 Biofuel developments in Africa

Biofuel production in Africa is still in its infancy. However, the region has some significant experience in commercial bioethanol production, although most of the bioethanol is for industrial applications. Still less than 1% of the world's total ethanol (all grades), about 638 Ml is produced in Africa [FO Lichts, 2007]. Apart from bioethanol production and use in Malawi, there has been no sustained biofuel programme in Africa. Currently there are numerous biofuel initiatives in many SSA countries but there is limited experience with large scale production and use of biofuels in the region. Hardly any commercial scale plants have been established. A number of projects and programmes are under development though.

South Africa passed a national biofuels strategy in late 2007, and is expected to expand production of sugarcane and other crops to create ethanol and soybeans and sunflower for biodiesel. Malawi has fostered a sugar-based ethanol programme since the 1970s. Zimbabwe and Kenya had some experiences with bioethanol blending in the 1980s, but abandoned the programmes for different reasons. Ethiopia has some ethanol production facilities. Benin, Burkina Faso, Cote d'Ivoire, Guinea Bissau, Mali, Mozambique, Niger, Senegal, Tanzania, Togo, and Zambia are among countries that currently explore new opportunities in bioenergy.

4 SUCCESSFUL DEMONSTRATION/PILOT SCHEMES

Although technologies for the production of bio-ethanol and bio-diesel from biomass feedstocks have been known for a long time, there are very few experiences of wide scale commercial production and use of these resources as transportation fuel in Africa. While the region can boast of having some of the most efficient sugar industries capable of producing fuel grade bioethanol, this capacity has not been translated into full exploitation of this resource. Production of biodiesel from such plants as Jatropha Curcas has also recently received a lot of attention in the continent. However, Jatropha based biofuel initiatives have been limited to the small scale cultivation of the Jatropha plant, extraction of oil from the Jatropha seed, and small scale production and utilisation of the pure Jatropha oil as fuel for transport, rural energy service provision and soap production. Although this technology is still yet to be applied on a wide-scale basis, significant political enthusiasm has been expressed in a number of countries. Many African countries have initiated some exploratory activities to develop biofuels, but there are worries that lack of experience in such activities may compromise the sustainability of the programmes. It is important therefore that knowledge from pilot activities in the region and elsewhere in the world be shared to overcome potential implementation challenges.

Implementing biomass energy technologies in a sustainable and socio-economically acceptable way in developing countries takes more efforts than in industrialised countries. This is mainly due to various barriers that hinder the implementation of such initiatives. Barriers encountered in various case studies differ by region and setting, but the most prevalent barriers include adverse market conditions (i.e. demand, prices, competition) although technical barriers are also important.

Fortunately, there is already a lot of experience gained through demonstration/pilot projects in various countries. A number of Latin American and Asian countries have gained considerable experience over the past few years. However, the lessons learned are not very well disseminated. Generally, demonstration projects are commonly targeted to overcoming market barriers such as market accessibility, market conditions, cultural aspects and education aspects. On the other hand research and development (R&D) projects are typically undertaken to address technical barriers.

This section discusses some selected pilot/ demonstration projects in the three continents with the aim of obtaining some insights into the best practices in implementing energy crop and biofuel programmes in developing countries. Replication of such successful initiatives would however need to be aligned with the local context. Programmes need to be well adapted to local needs and possibilities – for instance in terms of affordability and access to finance of end users or capacity to maintain the installed systems.

4.1 Biodiesel pilot projects

4.1.1 Breeding Jatropha as a sustainable energy crops for Hispaniola[1]

This project is being undertaken by the Centro Hispaniola de Investigacion en Bioenergias y Agricultura Sostenible (CHIBAS). It aims to evaluate the genetic resources of the tropical shrub Jatropha as an energy crop suitable for marginal and degraded lands of the tropics and to establish a corresponding breeding program along with the establishment of good agronomic practices for this new crop management. The program is aimed at the release of improved Jatropha varieties and corresponding seed and propagation technologies along with the best agronomic management practices that will allow for the development and establishment of successful Jatropha agro-systems.

Specific objectives of the project include:

- Establishment of an efficient Jatropha germplasm repository (live collection) and the development and release of germplasm (new improved varieties) adapted to the new needs for oil and biodiesel production.
- Systematic evaluation of the germplasm and making the results readily available. This germplasm will be evaluated for traits such as seed toxicity, oil content as percentage of dry matter, high oil oxidative stability, protein content, resistance to pest and diseases and traits enabling the mechanization of fruit harvesting.
- Releasing Jatropha varieties aimed at biofuel (biodiesel) production and adapted to the marginal areas and degraded land of tropical countries.
- Characterization of Jatropha yield components and identification of genes/alleles maximizing all desirable traits.
- Through breeding and the use of all available techniques, the project will pyramid these alleles into ever more productive Jatropha varieties.
- Development and evaluation of inexpensive mass propagation methodologies for clonal reproduction or improved hybrid seed production in order to cheaply mass produce plantlets for farmers.
- Evaluation and establishment of the most appropriate agronomic practices under different scenarios (low input agriculture or maximization of production/cost ratio)

Need for breeding Jatropha

Plant breeding is the most cost-effective way to achieve an increased and stable yield. While native Jatropha or outstanding individuals that can readily be cloned offer an already-substantial yield and drought tolerance, plant breeding would allow for continuous increase and release of ever more productive varieties. In industrial terms, this increase will translate to, for example, oil with increased oxidative stability and other properties that will lower the cost of making biodiesel and enhance its quality. Varieties with higher oil content in percent of dry weight will also provide increased revenue per working-hour for the farmers. The development of non-toxic varieties will allow farmers

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[1] Based on CHIBAS [2008] web link *www.chibas-bioenergy.org/en-web-jatropha.pdf*

to have additional markets for their product (not just biodiesel). Jatropha cake meal is protein rich, making it a highly attractive animal feed. Making Jatropha seeds edible will increase its economic value (two income-generating products instead of one). The 'green revolution' for major cereals would not have been made possible without the release of outstanding varieties. A new green revolution will require also new outstanding energy crop varieties.

Low cost mass propagation methodologies

Jatropha can be propagated through seeds, plantlets from tissue culture, from grafting and finally from cuttings. Grafting shortens time to maturity and harvest by 4 months allowing individuals to yield within the first year. Cuttings and tissue culture allow for the rapid mass production of plantlets.

The project aims at testing and developing the required technology and techniques for mass seed and/or plantlet production. Effect of these strategies on agronomic performance, yield and drought tolerance will be evaluated. Developed methodologies will be published and made public (free to use) to ensure that adequate training is provided to partner NGOs, seed companies, private sector partners, and farmers organizations for mass seed or plantlets production. The focus will be on methods for mass production of cuttings and scions along with efficient root production methods in order to provide an inexpensive technology capable of producing large amount of plantlets to the growers.

Crop management aspects

Jatropha agriculture will require establishing the methodologies for managing this new crop. CHIBAS will establish research in areas such as intercropping, pruning, use of bee hives to enhance fruit production, minimization of agricultural input, maximization of production/cost ratio (best use of agricultural input), and finally mechanization of harvesting.

Networking and international exchanges on Jatropha

CHIBAS has already established contacts and initiated collaborations with a number of international partners interested in establishing a Jatropha research community. These include researchers at Cornell University and Texas A&M University in the United States of America, Tamil Nadu University and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India.

4.1.2 Remote Village Electrification in India through Jatropha based Biofuels[2]

A leading effort is the initiative of Winrock International India (WII) to electrify one remote tribal village through the use of biofuel using non edible oil derived from tree

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[2] Based on Altenburg, et al [May 2008] and Practical Action Consulting [January 2009]

borne oil seeds in the state of Chattisgarh. The objective of this initiative was to demonstrate the technical and financial viability of running diesel generation sets using vegetable oil instead of conventional diesel to electrify a remote village. The initiative aimed to design and implement a replicable model of remote village electrification via biofuels. The project village, Ranidehra is in the Kabirdham district of Chattishgarh. Ranidehra is a poor predominantly tribal village of 110 households. These tribal communities mainly depend on subsistence agriculture for their livelihood.

Recognising the difficulty in energy access of the remote village, WII with the support of Ministry of New and Renewable Energy (MNRE) and BHC set out to illustrate the direct use of Jatropha oil for rural electrification. With the assistance from the Kabirdham district Administration, WII selected Ranidehra as the most suitable site to experiment.

The private sector was also involved in the project. For instance PM Diesels (Field Marshal) provided the necessary equipment while Castrol India supplied the lubricant that enabled the use of conventional diesel engine with some necessary modifications to produce electricity. The project initiation phase required some serious efforts to convince the local community about the project feasibility. A series of community mobilisation efforts and awareness generation camps resulted in the formation of a Village Energy Committee (VEC) and a women's self help group (SHG) in the village. VEC had decided to undertake Jatropha plantations in the barren land, private farm bunds, kitchen gardens etc. Successively, 24,000 Jatropha saplings were planted in the first phase and 20,000 in the second. Villagers put together Voluntary labour to plant the saplings and WII paid for the sapling costs. The saplings were sourced from the Forest Department. The land for the establishment of power house has been leased to the VEC by the district officials on request from the local Panchayat.

The power house comprise of an oil extraction section, a power generation room, a rice de-husking chamber, a power distribution room and a large storage area for Jatropha seeds and food grains. The oil extraction section comprises of an oil expeller and filter press. The power house is strategically located so as to enable equitable power distribution and equidistant transmission line extension to the hamlets and easy accessibility. The power house also serves as the place for village meetings. The power unit uses one tonne of oil seeds per month for 3 hours of domestic and 3.5 hours of street lighting per night. However, seed supply from Ranidehra and neighbouring villages is inadequate to meet daily the demand for power generation. WII therefore provides the necessary funds to purchase additional seeds from open market to meet demand.

Press cake from the Jatropha seed processing is sold in the open market as a domestic fuel and to fuel small scale commercial ventures such as brick making. CREDA is testing the possibilities of using the press cake to generate biogas. Use of press cake as green manure is still under scientific scrutiny owing to uncertainty as to its possible toxicity.

This pilot initiative with technical support from the private sector confirmed the successful utilisation of Jatropha oil directly as fuel. It also brought a successful partnership between WII, equipment and lubricant provider and the public sector.

Further, community mobilisation effort by WII established VEC for the proper administration and operation of the initiative. VEC is a registered body consisting of 14 members including 6 women. Members of the VEC are representatives from the local community and are elected to the committee. Seed collection operation is monitored by VEC while woman SHG assists VEC in seed collection. Electricity users pay the VEC in cash monthly for energy usage. $0.44 per 11 Watt Compact fluorescent light bulb and $0.67 per plug point is collected from the villagers. The villagers also benefit from the rice de-husking machine which charges $0.55 per 50 kg of rice whereas it costs $1.55 for the services of the nearest rice mill in the town.

The cultivation of the Jatropha is done on private land and also on road sides. To increase supply of seed, there are plans to increase the area under plantation and improving management.

4.1.3 Selected Biodiesel trials in India

4.1.3.1 Sustainable Transformation of Rural Areas

Sustainable Transformation of Rural Areas (SuTRA) was a Global Environment Facility (GEF) project with the objective of demonstrating the possibility of biofuel packages for meeting the energy needs of rural households and agriculture. One of the technology options selected was the direct use of pongamia, neem and cottonseed oil to generate power in small stationary diesel engines (5 to125 hp) for drinking water and irrigation. The demonstration was carried out in ten villages and hamlets of Tumkur district (Karnataka) during 1998 to 2001. It is reported that Operation and maintenance (O&M) costs with SVO were higher compared to diesel. But no scientific data was available to arrive at the exact O&M requirements [TERI, 2005].

4.1.3.2 SVO as transport fuel: Karnataka State Road Transport Corporation (KSRTC) experience

One of India's largest public transport service providers KSRTC – has successfully conducted trials on 10% SVO blend in buses. With a fleet of 4000 buses, it started trials on the use of pongamia oil in its buses around 2002. After initial testing on old buses, experimental trials on 10% oil blend in 2 new buses were taken up in 2004. The performance of these buses was compared with 2 new buses running on diesel on the same route. Initially, problems were faced in achieving proper mixing of pongamia oil with diesel, which was solved by adding an enzyme-based additive with simultaneous agitation at 200 rpm. The cost of the additive is INR 2200/litre and 1 litre of additive is added in 6000 litres of fuel [TERI, 2005].

According to KSRTC, an overall efficiency (mileage) improvement of 12.5% in comparison with diesel has been observed; though maintenance costs are slightly higher as fuel filters are now replaced after every 8,000 km, compared to 10,000 km on diesel operation. In addition, the current market price of pongamia oils INR 28/litre compared to price of diesel at INR 37/litre. Even with the additional cost of INR 3.67/litre for the enzyme-based additive, as well as costs for more frequent replacement of fuel filters, KSRTC has estimated an overall saving of INR 3/litre by using the blend over diesel [TERI, 2005].

KSRTC has monitored the performance of two vehicles during the trial runs and encouraged by the results plans to operate the entire fleet of Doddaballapur depot (82 buses) near Bangalore on this blend. It has plans to extend the use of blends to 10 more depots in near future.

4.1.3.3 Daimler Chrysler trials

Daimler Chrysler carried out trials with 100% Jatropha biodiesel on two Mercedes-Benz C220 CDI cars during 2004. An Indian research institute, Central Salt and Marine Chemicals Research Institute (CSMCRI), supplied 1,200 litres of Jatropha biodiesel for the trials. No major engine modifications were carried out and one of the vehicles successfully covered 6,000 km without any problems. The average mileage during the trip was 13.5 km/litre, which is comparable to that with fossil diesel [Daimler, 2008].

4.1.3.4 Other trials in India

Another important trial was conducted by Indian railways on a diesel locomotive (16 cylinder Alco DLW, rated at 3100 HP) using 5,000 litres of imported soybean biodiesel blends (B10, B20, B50, B100) during April-May 2004. The state road transport corporations of Haryana, Gujarat, Andhra Pradesh and Indian vehicle manufacturers - Tata Motors, and Mahindra & Mahindra are also carrying out trials with biodiesel blends [TERI, 2005].

4.1.4 The Garalo commune Jatropha fuelled Rural Electrification Project in Mali[3]

In Mali, 99 % of the rural population lacks modern energy services such as electricity and LPG. It is highly unlikely that the government can support rapid changes to energy access in the short to medium term. The Garalo project is aimed at addressing these challenges at a community level. If proved successful the pilots will be scaled up given the huge land potential. Garalo, where the pilot is located has about 19,800 inhabitants of different ethnic communities.

This initiative was largely funded by a grant from AMADER, a parastatal company in charge of rural electrification, and an international non-governmental organisation, the FACT foundation. When the project was initiated, there was little information on the use of biofuel and its impact on engines. There was also a lack of knowledge about engines designed to work only with pure vegetable oil. Despite these constraints the Garalo project gave priority to biofuel development and more specifically to Jatropha, chiefly because this is a model in which village natural resources (land and Jatropha) are

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[3] Based on Janssen and Rutz [2008], UNDESA [2007] and Practical Action Consulting [January 2009]

processed and used locally, contributing thus to energy security and increasing the added value for local communities.

A series of other key reasons explain the choice of Jatropha development for electricity generation. Mali is the most experienced West African country in this field. With the support of GTZ, Mali carried out several pilot projects during the beginning of the 90s including equipment testing. The dramatic increase of oil prices and the biofuels investment world wide by large companies were instrumental in the re-development of Jatropha programmes in Mali which received a strong political support from the government. The inter-cropping model which is being largely used, contributes to limiting the negative impact on food security.

With respect to the enabling environment, the national energy policy strongly supports development of Jatropha for energy end uses. Local Authorities are playing an important role particularly thanks to their power to enact municipal by-laws. The Jatropha supply chain is being developed by two main institutions: The Garalo Jatropha Producers' Cooperative (CPP) and the power company ACCESS.

Jatropha farmers are at the heart of the business model supplying biofuel to the hybrid power plant. The CPP deals at the level of the commune with all issues regarding Jatropha seeds, production and sale of pure vegetable oil as well the residues (oil cake) as a fertilizer. In order to operate efficiently in all the villages, farmers, with the support of Local Authorities, have set up Jatropha producers village committees (CVPP) to deal with the key activities at the village level for instance seeds collection and transport to the cooperative.

Out of a forecast of 10,000 ha of Jatropha, 600 ha, involving 326 rural families are already under cultivation. Many plantations are on land previously allocated to cotton. Farmers have opted for the intercropping production mode to ensure food security at least at the village level. The residues of Jatropha seed processing can be used as a fertilizer. It is also envisaged to make an energy use of the oil cake to produce biogas.

The private power company ACCESS is responsible for generation and electricity sales. ACCESS has a capacity of 300 kW with a distribution network of approximately 13 km and with the prospect for an extension of 3 additional kilometres. Currently 247 households are connected to the micro grid after a payment of $30 as a contribution to the connection costs. As for electricity consumption, there are two broad tariffs categories. Subscribers with 50, 150 and 300 W are paying a monthly lump sum for their electricity consumption which is respectively $5, $12 and $24. In addition there is a modest monthly contribution for street lighting which is 0.07 cents, 0.16 cents and 0.30 cents according to the power. Other subscribers with higher power and theoretically higher purchasing power, are billed according to their metered consumption at a tariff of 38 cents/kWh. In addition, they have also to pay fixed charges and higher contribution to street lighting. It is worth mentioning that the first 100 kWh are exempted from the VAT payment. The tariff structure is largely due to AMADER which is providing a large grant (approximately $379,750) and is concerned by the power plant sustainability. Despite these relatively high prices, the recovery of the bills is over 90 % which demonstrates the willingness to pay for modern energy services. Customers who do not settle their bill on time were offered the option to delay the payment till their financial situation improves. Currently ACCESS has been able to recover almost 100 % of the recurrent costs.

In terms of Supporting Services, apart from its coordination and mediation function, Mali Folkecenter (MFC) has been supporting the Jatropha committees by setting up nurseries and distributing Jatropha plants through the village committees (CVPP), training, and other means. This is a crucial technical and financial input to the farmers. For the follow-up and evaluation, FACT foundation is providing its services to MFC. Other supporting services include the hybrid power plant equipment provided by a Dutch company and the locally manufactured press.

To encourage ownership of the Jatropha production system by the rural communities, the social and business model was developed with strong involvement of the local authorities. For instance given the competition regarding Jatropha seeds, local authorities have prohibited their sales outside the commune to secure a sustainable supply for the hybrid power plant. Currently the supply at national level is very low compared with demand. A by-law was passed to ensure that local production is entirely devoted to the power plant. Jatropha production village committees were set up in 33 villages including 30 in the commune of Garalo and the three others are in another commune (Sibirila) close to Garalo. A co-operative of producers (CPP) encompassing all the villages has been set up for the purchase, commercialisation and processing of the Jatropha seeds by a co-operative owned press. The co-operative is also responsible for the distribution to its members of the revenues generated by these activities on average twice a year. The agreed current price is currently 9.8 cents per kg which should allow both a reasonable margin for the farmers and a competitive selling price of Jatropha oil. The seeds will be processed by the co-operative and sold to ACCESS.

ACCESS, the power company, is a MFC subsidiary with a commercial status, thus management and procedures are completely different from MFC which has NGO status. MFC and Fact Foundation are providing technical support to the power plant operator ACCESS and to the Jatropha producers’ co-operative.

The whole model is based on the land ownership of small-scale farmers and the availability and status of the land. Even if the quantities cultivated remain modest, the Jatropha plantation growth rate is fast both at national level and in this commune. This is mainly due to the prospects raised by some large foreign companies, as well private entrepreneurs, to buy and process the seeds to produce biofuels either for the local market and/or for exports. As a result, there is a significant demand from many farmers to plant Jatropha, collect and process seeds for energy purposes. The main socio-cultural constraint is the status of the farmers and the land. Some have only the right to cultivate (usufructuary or tenants for life) either collectively or individually but they are not fully-fledged owners. As long as the usufructuary only grows non perennial short rotation plantations, the possible conflict between owners and usufructuaries is low because the investment is made on a short-term period. However, the plantation of trees is an investment over several decades. In Mali, according to customary law, it is considered that land planted with trees definitively belongs to the person or community who planted the trees. This explains the opposition of landowners to authorize migrants to plant trees including Jatropha as they may lose their landlord status.

The co-operative (CPP) is responsible for all the technical, commercial and financial issues in the supply chain from the raw material (Jatropha seeds) to processing to obtain biofuel. Currently, co-operative members are benefiting from guaranteed although fixed prices for seed production. In a region with little opportunities for cash generation, this is an important economic and social safety net. In the unlikely event of a sharp fall of oil prices and diesel oil, the farmers might encounter some difficulties to sell their seeds. On the other hand, an increase of oil prices may give some margin for the co-operative to negotiate higher prices with the power plant's owner. The other key issue regarding rights is related to independent power producers, such as ACCESS, which now have the right to produce, transport and sell electricity. In order to limit the monopolistic situation of ACCESS, an Electricity Consumer Association (ECA) was set up to look after the rights of the consumers and acts as an interface between the consumers and ACCESS. Although ECA does not have a legal status, it is recognised, de facto, by local authorities and attends the meetings to discuss the tariffs alongside with the key stakeholders, particularly local authorities, AMADER and ACCESS. It is AMADER's responsibility to ensure that the subsidies are being used efficiently and according to the procedures, including tariffs, by the recipients.

4.1.5 Multifunctional Platforms and Jatropha Oil Production in Tanzania

In 2006, the Tanzania Traditional Energy Development and Environment Organisation (TaTEDO) began piloting multi-functional platforms (MFP) for productive uses in Tanzania. The objectives of the project were to: install three MFPs and associated machineries for oil seed extraction, grain dehulling/milling, and battery charging; bring knowledge and capacity to the development and implementation of MFP projects in Tanzania; develop capacity among beneficiaries on the use of MFPs, management, and small business development; and demonstrate to policy makers, investors, and donors that innovative solutions can provide improved energy services.

The first MFP was installed in Dar es Salaam at one of TaTEDO's organisation centres for training and information sharing purposes. Others have been installed in Engaruka village located in Monduli district, and in Ngarinairobi Village in the Arumeru district. The platform engines run on Jatropha oil as well as on diesel during times of Jatropha shortages. When operating on diesel, the running costs are nearly twice that of the Jatropha oil. In the long run the platform will run entirely on the oil extracted from the locally grown Jatropha seeds. TaTEDO is also training and promoting the growing of Jatropha plants in the region to ensure availability of Jatropha seeds.

The MFPs are run commercially by a local entrepreneur selected by the villagers. This individual is responsible for running the MFP, collecting connection/service fees, and ensuring platform maintenance. The entrepreneur has been trained on operation and management of the MFP and provided enterprise development skills to run the MFP sustainably. Experience shows that the platform is more efficient when run and managed by a local entrepreneur rather than an outside organisation. Recently, one entrepreneur has established a battery charging and lightning service.

Benefits from the program include the following:

- MFP systems have been appreciated by the villagers, particularly women;
- use of locals skills and resources has been enhanced;
- the MFP has been integrated into the local economy and adapted to beneficiary/customer needs; and
- the system is offering crucial social and economic community services, including extended business and working hours.
- The MFP has provided electric lighting, maize dehusking, and jatropha seed pressing.

The project has resulted in MFP being installed and operated at three sites; a village mini-grid has been constructed; 50 households have been connected to the grid (at US$3 per month, flat rate); 12 shops have been connected to the grid (US$5 per month); operators have been trained and entrepreneurs supported; 20 households are now accessing electricity through battery charging; and there is possibility of more modules connected on demand.

Challenges for replication include:

- organized availability of quality seeds which is not presently available,
- lack of awareness on Jatropha plants/benefits,
- no clear source of Jatropha information in the country,
- oil expellers not readily available,
- lack of ingredients for local biodiesel processing (i.e., methanol),
- biofuels policy not yet in place.

TaTEDO is working to address these barriers.
The project is expected to expand to cover over 200 villages, as well as improve Jatropha production/marketing. Income through carbon sales is to be pursued while advocating for promotion of supportive policies/regulations. The project is expected to increase public awareness while integrating biofuels into the country's overall sustainable rural development efforts.

4.1.6 Jatropha based biofuel production in small scale farmer communities in Thailand[4]

In 2006, the University of Kasetsart began working with 500 farmer members of the Viengsa Agricultural Cooperative to develop Jatropha, primarily for biodiesel production.

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[4] Based on Practical Action Consulting [January 2009]

The rationale behind the project was that Jatropha could form the basis of a community-level income and employment generation programme.

The Jatropha supply chain has been developed by two main institutions: The University of Kasetsart and the Viengsa Agricultural Co-operative. The University of Kasetsart initiated the project, identified the key partner - the Viengsa Agricultural Co-operative - and secured the necessary funding. Viengsa Agricultural Co-op was established in 1970 to help farmers reduce the cost of production and today has around 6,000 members.

$100,000 funding was secured to provide training for farmers in land and seedling preparation, transplanting and spacing, water and pest management, fertilizer application, harvesting, drying and storing and equipment for Jatropha production. The project was started in 2006 and is expected to run for five years. Out of a total 5,000 co-operative members, more than 1,000 farmers have now been trained on Jatropha production.

Thailand’s government has an ambitious target to increase the renewable energy share of commercial primary energy to 8% by 2011 through its Strategic Plan for Renewable Energy Development. In 2006, the Government produced a roadmap for biodiesel and bioethanol production. The biodiesel roadmap sets out a vision for 2012 when it is anticipated that production capacity will be sufficient to serve the entire nation. Initially the roadmap is to focus on community-based biodiesel production for local use.

To ensure economies of scale, sufficient number of farmers in the Viengsa Co-operative had to be drafted to grow Jatropha hence the co-operative model was selected for this project. A particular advantage of the Viengsa Co-op is that its members receive a soft loan to buy the raw materials required for crop production from the seed retailers (also Co-op members), thus making it easier for farmers to be involved.

The Co-op and it members are the principle market chain actors in this project and their working relationships are key to its success. Once harvested by the farmers, the seeds, hulls, leaves and stems are sold on to other members of the Co-op for processing. Biodiesel is sold to members of the Co-op about 20% cheaper than open market cost, with priority going to those members who need fuel for tractor engines.

Organic fertilizer is channelled for use by community members on crops such as rice, vegetable and fruit. Charcoal is sold direct to households for use in cooking. A community micro power plant is also to be established and will serve five to ten nearby communities within a 50 km radius. It is also anticipated that paper fibre, particle board and handicrafts can also be produced for sale.

In terms of Supporting Services, the University established and runs the Jatropha School which provides training on Jatropha production and processing into marketable products. No fee is charged to the farmers for attending the Jatropha School. By September 2008, more than 5,000 participants had graduated from the school. The project has also trained participants to design and construct machinery to process the various parts of Jatropha into products to suit different scales of production. The Co-op provides supporting services to its members in term of access to soft loans, technical support in seed production from extension officers and technology support to the biodiesel processors.

Relationships between the different co-operative members are formalised via contracts established and overseen by the Co-operative Committee. These agreements fix and guarantee prices for raw materials and Jatropha products. Farmers are guaranteed fixed prices for their crop by the Co-operative at \$0.20/kg for seeds and \$0.01/kg for hulls or leaves or stems.

4.1.7 PROVEGAM – Demonstration of the utilization of straight palm oil for power generation in Brazil

PROVEGAM[5] is a project which tested the use of straight palm oil as a fuel for generating electricity based on a conventional diesel generator set, coupled to a conversion kit. The main function of the conversion kit is to heat the palm oil so as to reduce its viscosity and to control the flow of palm oil and mineral diesel (which is used for starting as well as at the end of the engine's operation).

The objective of PROVEGAM is to install, test and evaluate, in real operational conditions, the operational functioning of a 115 kVA diesel genset run on straight palm oil. This project targeted a remote community of up to 100 households as its market which had previously been served by an 85kVA diesel genset. Ultimately, if this pilot project is successfully, it is hoped that the technology can be replicated to support rural electrification in isolated Amazonian communities.

The project was initiated by the University of Sao Paulo, Biomass Users Network, Secretariat of Energy (Sao Paulo State), and the Ministry of Science and Technology (Federal Government). Financing was provided by FINEP, the federal agency in the Ministry of Science and Technology while a private company Agropalma supplied about 40 m^3 palm oil for the tests. CENBIO was in charge of carrying out all the activities such as performance and durability tests of the diesel genset using pure palm oil as fuel; development of a system of storage and feeding of palm oil as well as emissions tests.

Although the project was successfully executed, there were initially some compatibility problems with the imported kit. It was therefore necessary to adapt the kit to local conditions. Due to its success, the federal government is using the results from this project as input to analyse different options for rural electrification of isolated communities in the "Luz para Todos" (Light for everybody) national electrification programme. Another project, code-named PROVENAT, is being developed and aims to replicate electrification through vegetable oils utilization in Amazonian communities.

Electrification in the Amazon region is currently very low as a result of the traditional Brazilian model centralised grid based electricity supply. Rural electrification in this region is based on isolated diesel gensets incurring high transportation costs of fossil fuel

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[5] This project is described in more detail in Developing Renewables [2008].

in the process. As a result, electricity access is very low and services are costly. Hence, there is scope for utilizing vegetable oils in electricity generation.

Amongst the cultivated plant species in the Amazonian region, the palm *(Elaeis guineensis)*, species of African origin is suited for Amazonian climate conditions, given its high oil productivity (3-5 t/ha) and other by-products, such as animal feed, fertilizer, etc. It also has advantages regarding its ability to grow in marginal soils and thereby rehabilitate degraded soils. In addition, there are opportunities for employment creation and income generation, thereby helping to reduce rural urban migration. The project has also led many families to acquire machines to processing açai (a tropical fruit), to generate income and commercialising the fruit.

4.1.8 Continuous palm oil transesterification

According to Thamsiriroj [2007] the Malaysian Palm Oil Board (MPOB) has developed a production technology of PME (palm oil methyl ester) through the continuous process, where the unrefined oil, crude palm oil with a high free fatty acid level (typically of more than 1%), is enabled. The process consists of the esterification of the free fatty acid (FFA) present in the crude palm oil into methyl ester, transesterification of the triglyceride into methyl ester, products' separation and purification. The process is present in Figure 2.

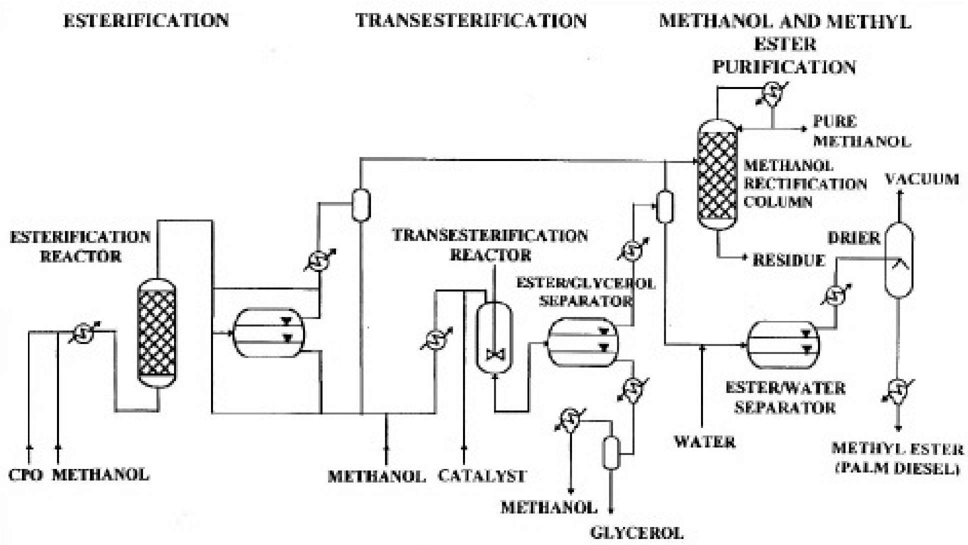

Figure 2: PME through the continuous process
Source: Thamsiriroj [2007]

In the esterification stage, crude palm oil containing FFA is mixed with methanol and heated to the reaction temperature. The mixture is fed into the esterification section consisting of a fixed bed reactor filled with the solid catalyst. The reaction temperature and pressure are maintained at 80°C and 300 KPa. After the esterification reaction, the reactor effluent is allowed to settle into two layers.

The lower oil layer is then transferred to the transesterification section and the upper methanol layer is sent to the methanol purification section. In this transesterification stage, the reactor is operated at 70°C with excess methanol and in the presence of a catalyst. And the last stage includes the washing of the ester with water to remove traces of impurities, e.g. glycerol, soap, and NaOH. Sodium chloride (NaCl) is used to break the emulsion. After washing, the ester is then dried in a vacuum dryer before being pumped to the storage tank.

4.2 Bioethanol projects and experiences

Bioethanol production and trade has been centred in Brazil where large scale ethanol production from sugarcane, together with the increasing fleet of flexfuel vehicles, has become a model for biofuel production and use. However, there are some noteworthy experiences in other parts of the developing world including Sub-Saharan Africa as well as in Asian countries such as China and India.

By their nature bioethanol production undertakings are capital intensive and demand large scale development to allow economies of scale[6]. Except for second generation technologies, bioethanol production is a mature technology. Hence, most ethanol investment projects are undertaken already on commercial basis. In addition, innovation is primarily incremental to existing infrastructure through retrofitting and technology upgrade to increase efficiency, etc. However, there are some experimental projects along the value chain such as improvements of yields in the agronomic phase as well as new feedstock development and testing.

4.2.1 Bioethanol development in Brazil

Brazil has been a pioneer in the development of bioethanol as a transport fuel and has accumulated significant experience and expertise since the National Ethanol Programme (PROACOOL) was initiated in 1975. Following the first oil crisis, Brazil launched PROALCOOL, creating the conditions for large-scale development of the sugar and ethanol industrial supply structure as well as creation of a market for blended petrol and anhydrous ethanol. Incentives were also provided for the development of vehicles that were fuelled exclusively with hydrated or neat ethanol. In the process, this would reduce oil imports, stabilise the sugar market and create thousands of jobs. From 1975 to 1979, anhydrous ethanol for gasoline blending was produced in distilleries annexed to existing sugar mills. By 1979, ethanol production had increased from 600 million litres to 3.4 billion litres per year. In 1979, following the second major oil shock, a more ambitious programme was implemented, promoting the development of new sugar cane plantations, new autonomous distilleries and a fleet of purely ethanol-fuelled vehicles. A series of tax and financial incentives was introduced. In addition, the production and distribution of

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[6] According to Johnson and Matsika [2006], the minimum efficient scale of feedstock for bioethanol production has been estimated in Brazil as 2 million tonnes of sugar cane per year.

hydrous alcohol was subsidised. The retail price of ethanol was set to 50% of the gasoline price with a guarantee not to exceed 65% of this price. Convenient financing schemes for purchasing neat ethanol cars were also provided. Buoyed by these measures, neat ethanol vehicles rose to about five million and ethanol production rose to over 7 billion litres in 1985 [Moreira, 2004].

Subsidies provided through the programme were intended to be temporary, as high oil prices were expected to make ethanol competitive with petrol in the long run. However, as international oil prices fell in 1986, the elimination of subsidies became problematic. In addition, rising sugar prices led to scarcity of ethanol, and in 1989 severe shortages in some of the main consuming centres undermined the credibility of the programme [GBEP, 2007]. Between 1989 and 1996, Brazil imported about 600 million litres to meet local fuel demand [Moreira, 2004].

From 1989, deregulation of the sector begun by dismantling government economic incentives. In 1990, the Sugar and Ethanol Institute, which had regulated the Brazilian sugar and ethanol industry for over six decades, was disbanded, and the planning and implementation of the industry's production, distribution and sales activities were gradually transferred to the private sector. With the end of the subsidies, the use of hydrated ethanol as fuel diminished drastically. However, the anhydrous ethanol market was boosted with the introduction in 1993 of a 22% mandatory blending requirement for all retailed petrol. The blending requirement is still in place today, with the Inter-Ministerial Board for Sugar and Ethanol establishing the required percentage, which can range from 20 to 25% [FAO, 2008].

By the end of the 1990s, fuel prices were liberalized and by 2000, the sugarcane industry was full deregulated, marking an end of the PROALCOOL era. While the government no longer directly subsidises ethanol production, certain tax incentives still exist, including lower taxes on alcohol fuel, lower taxes on neat ethanol vehicles, and financial incentives to distilleries to encourage them to hold larger alcohol inventories. Including these incentives, the retail price of ethanol is only about USD0.10 (USD0.15 per gasoline-equivalent litre) [IEA, 2004a].

4.2.2 Bioethanol development in Zimbabwe

Plans for a fuel ethanol plant in Zimbabwe began during the 1970s when the country was under international sanctions. Zimbabwe's land locked position, political vulnerability of supply routes and foreign exchange limitations also influenced the development of the fuel blending programme. Also, around 1978, international sugar prices were poor and molasses was in surplus. Even though the 40 Ml Triangle ethanol plant started operating in 1980, when sanctions had been lifted, disruptions of oil supplies through Mozambique (due to civil war) meant an alternative fuel source was still vital [Scurlock *et al.* 1991].

A number of factors contributed to the relative success of the Zimbabwean ethanol programme, key among which was the effective technology transfer and adaptation of plant design, close working relations between government and private sector and optimization of local resource use. The plant was locally planned with local control over its running even though the design was by foreign experts. All decisions concerning the construction of the plant were made locally. With government support and partnership the industry was able to select low-cost technology closely tailored to its needs. This enabled Zimbabwe to build an annexed distillery at a capital cost of USD_{1980} 6.4 million - the lowest capital cost per litre for any ethanol plant in the world [Habitat, 1993].

To enable the establishment of a plant that could be run by domestic labour, manual technology was chosen rather than sophisticated automation. For instance, it was decided to build a standard batch-type fermentation plant which could be operated by existing staff at the sugar mill. Instead of importing distillery components, the locally-available fabrication structure was exploited. Consultants provided technical assistance where necessary, but a remarkable 60% of the plant was fabricated and constructed in Zimbabwe. Only specialist items such as plate heat exchangers, an air blower and instrumentation were imported. To ensure high standards, local welders were given special training [Scurlock *et al.* 1991].

Although the government played no role in financing of the project, it strictly controlled the foreign exchange. Financing of the plant was mainly local. A well developed agricultural and industrial sector enabled cost effective feedstock production and manufacture of most of plant equipment at low cost. The food-fuel dilemma was then not critical because Zimbabwe produced excess food. All the ethanol produced was sold to a government controlled fuel procurement agency (NOCZIM), which then resold to oil companies for blending and distribution, removing risks from the producer [Scurlock *et al.* 1991; Habitat, 1993].

The Triangle ethanol plant was designed to operate on a variety of feedstocks using different grades of molasses, cane juice, or even raw sugar. This flexibility means that the plant was fully integrated with the rest of the sugar production process and allowed Triangle to shift sucrose to either more raw sugar production or ethanol depending on relative market prices, in order to maximize the return on total investment in both sugar and ethanol production. Typically, B-molasses from the Triangle sugar mill and additional C-molasses imported from neighbouring Hippo Valley Estates and from Zambia were used as feedstock. Triangle also bought cane from 150 local growers (small farmers and private companies). The ethanol blend varied between 8% and 18% depending on sugar harvests [Kartha *et al.* 2005; Habitat, 1993].

This programme was suspended in 1992 after a severe drought which drastically reduced sugarcane production and consequently affected molasses feedstock availability. Thereafter, attempts to resuscitate the blending programme failed due to changes in national economic policies. Economic reforms at the time and tax incentives in Zimbabwe were encouraging exports and Triangle found international buyers for potable alcohol (for spirits and liquor), which generally commands a premium price. Triangle also optimized the plant for more raw sugar production, resulting in minimal production of molasses and ethanol, and NOCZIM was reluctant to blend at a lower scale. Consequently, even though Triangle is again producing 30 Ml of ethanol per year, it is mainly sold on the potable market (mainly export markets) and is no longer blended with gasoline [Kartha *et al.* 2005].

There are plans to resuscitate the ethanol blending programme. Negotiations have been ongoing between Triangle and the government mainly over ethanol pricing. Tongaat Hullet, the holding company which owns Triangle, has recently announced that it intends to restart bioethanol fuel production [Hill, 2008].

4.2.3 Bioethanol developments in Malawi

Malawi has had the longest ethanol blending experience in Africa. It is the only country in Africa producing and using fuel ethanol, and one of the first to achieve a national blend of up to 20% ethanol. Ethanol production from sugar cane molasses and blending with petrol has been practiced since 1982. The ethanol programme in Malawi was motivated by the high oil prices as oil was imported by road via South Africa due to the war in Mozambique and this longer route coupled with currency devaluation which raised landed costs by 33% [Takavarasha *et al.* 2006].

The first ethanol plant (an annexed distillery with a capacity of 18 Ml per annum) was built at Dwangwa, one of the two main sugar estates in Malawi. The Malawian government played a much greater role in investment decisions of this plant than their Zimbabwean counterparts did for Triangle. Simple designs similar to those at Triangle and a thrust on utilizing local material were also employed for the plant. The plant cost about USD8 million to build and is reported to have saved the country about USD32 million between 1982 and 1990. Initially, the government provided a price guarantee of USD0.42 per litre of ethanol irrespective of production costs but this has now been revised and the price is now pegged against the landed price of petrol [Takavarasha *et al.* 2006].

Dwangwa ethanol plant is run by ETHCO Ltd. (Ethanol company of Malawi) and annual production has varied between 15-20 Ml while blending averages between 15-22%[7]. ETHCO is owned separately from the adjacent Dwangwa sugar factory, resulting in the need for price negotiations, additional costs, and increased uncertainty in feedstock supply (Unified ownership of ethanol plant and sugar factory at Triangle avoids these problems). Dwangwa sugar factory does not have sufficient feedstock and ETHCO has to secure up 40% additional molasses supply from the Sucoma sugar factory, located several hundred kilometres to the south. This worsens the energy balance and increases the cost of ethanol produced from Dwangwa as diesel trucks are used to transport molasses from Sucoma. But unlike the Zimbabwean plant which is affected by drought, sufficient irrigation water is available from Lake Malawi to maintain production at ETHCO [Kartha *et al.* 2005].

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[7] Malawi has phased out unleaded gasoline since January 2005, importing refined high octane fuel instead. Hence ethanol is now used as a gasoline extender, rather than as an octane booster replacing lead. The blending volume can now be reduced to 10%, thus reducing the annual requirement of ethanol for blending to about 10 million litres.

A second distillery with a capacity of 12 Ml of ethanol per annum was commissioned in June 2004 and is located in the south of the country at Nchalo sugar factory, and uses molasses feedstock from Sucoma's nearby sugar mill. This plant is being run by Press Cane, a joint venture between two Malawian companies, the Press Corporation, which is also the major shareholder in ETHCO, and Cane Products [Mhango, 2005; Karekezi *et al.* 2007; Press Corporation, 2007].

4.2.4 Sweet sorghum trials in Zambia

Potential for sweet sorghum production as a bioethanol feedstock in Zambia is being evaluated by the University of Zambia since the 2004/05 growing season. The project assesses the agronomic performance of sweet sorghum varieties in three agro-ecological regions of Zambia and on major soil types with respect to biomass production, sugar content and optimum time for stem harvest. The agronomic evaluation tested 9 (8 exotic and one indigenous variety called Sima) sweet sorghum varieties[8] in a randomised complete block design with four replications. Sima is a dual purpose sorghum developed for both grain and sweet stems which are used for silage [UN-DESA, 2007].

Major findings of the trials

Published results from the 2004/05 growing season show that the highest stem yields were obtained for TS1, followed by Praj1, GE2 and Wray. The increase of stem yields from booting to soft dough stage was only significant for Keller and GE2. Stem yields of 26,663 kg/ha for TS1 were comparable to those obtained elsewhere especially considering that these were obtained under partial drought conditions in the 2004/2005 growing season [Matsika *et al.* 2006].

Sweet sorghum yields varied with location, being very sensitive to the agro-ecological region. There was a two-fold reduction in stem yield in region III (the high rainfall region) compared to the other two regions. This is attributed to the acidic soil type of region III, and photoperiodic response. There was also an influence of soil type in region II, where the yield was generally lower on shallow and infertile soils. The stem and height also varied with locality, soil type and population density. In some cases, high population density resulted in thinner stems and therefore prone to lodging [Matsika *et al.* 2006].

Sugar content (as measured by Brix%) varied with the variety and the stage of growth as well as the environment. Accumulation of sugar content at different stages of growth was only reported for one site (at UNZA). Most varieties had reached the peak in sugar content by milk to dough stage, while Wray, GE2 and TS1 were still increasing; these were long season varieties whose growth was interrupted by drought during the 2004/05 season. The highest values of sugar content were obtained with Wray, Keller, GE2 and TS1. For most varieties, the sugar content was higher than the typical value of 11%,

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[8] Sweet sorghum varieties tested include Sima, Keller, Madhura, Praj 1, GE2, GE3, Wray, Cowley, TS1

which improves the potential ethanol yield which is directly proportional to the sugar content [Matsika *et al.* 2006].

Conversion to ethanol

Using a small-scale crusher, sweet sorghum juice was produced. The average juice extraction was 35%, with the remaining mass being 65% bagasse. It was encouraging to note that the minimum sugar content was 12.5%, while the maximum was 25.3%, the average being 18.2%. This result is interesting because the optimum sugar level for fermentation is around 15% to 20%. The varieties with the highest potential for mass cultivation are Wray and GE2, due to having not only high juice extraction ratio, but also high sugar levels. Wray had a juice extraction ratio of 35.1%, and 25.3 % brix, while GE2 had 37.0% and 21.7%, respectively. TS1 is another variety worth considering as it has a high yield of 27 tonnes stem/ha despite having sugar content of 20.0%, and juice extraction ratio of 32.1% [Matsika *et al.* 2006].

The results also showed that yields of some sweet sorghum varieties were competitive with sugar cane as three yields could be produced within 18 months in contrast to only one sugar cane harvest in the same period. This allows filling the off-crop season and year-round ethanol production.

These findings agree with the results obtained at National Agricultural Research Institute in India. One hectare of sweet sorghum in one year (two seasons) yielded: 2-4 tons of pearly white grain; 5-7 tons of dry leaves; 15-20 tons bagasse; and 5-9 tons syrup (750 brix) or 3,000 to 4,000 litres of ethanol (95%). Thus, preliminary results show production of sweet sorghum could be integrated with sugar cane [UN-DESA, 2007].

4.2.5 Ethiopian clean ethanol stoves project

Since 2004, Project Gaia has been working to promote ethanol as a household energy fuel in Ethiopia. An 18 month pilot study funded by the Shell Foundation's Sustainable Energy Programme was conducted to test 850 alcohol stoves in households in Addis Ababa and in three refugee camps in Ethiopia. The aim was to make locally produced ethanol commercially available by introducing and market testing the 'CleanCook' ethanol (CC) stove, and by promoting government policy to support the introduction of this new household technology and fuel. Results of the pilot project by Gaia have shown that households readily accept the CC stove, and ethanol could effectively substitute kerosene, charcoal and fuel wood, thereby mitigating household energy scarcity while increasing stove safety and reducing indoor air pollution. [Debebe & Lambe, 2008]. This is part of a broader Ethiopian bioethanol initiative which includes an ethanol blending programme for the transport sector accompanied by expansion in sugar factory investments. Ethanol distilleries being built by the government have a promising potential to cover ethanol demand from both the household and transport sector.

In 2005, the Gaia Association was formed as an autonomous Ethiopian registered NGO. Its mission is to reduce risk and create opportunity for private business to take over.

Additionally, the association is working to scale up the number of stoves in use in the UNHCR administered refugee camps [ibid]. It began working with a private sector partner to facilitate local manufacture of CleanCook stoves, to reduce the cost of the stove to Ethiopian consumers. Work with the private sector partner is financed by the partner, Makobu Enterprises PLC, and by a 'commercialisation grant' from the United States Environmental Protection Agency (USEPA) under its Partners for Clean Indoor Air (PCIA) programme. This effort is also being assisted by Project Gaia, Inc., a U.S. donor-supported non-profit agency [Practical Action Consulting, 2009].

Makobu enterprises has imported and sold CleanCook under the project, and is now starting to produce stoves locally in a custom-built new factory near Addis Ababa. Stove production is supported technically by the original stove manufacturer Dometic AB of Sweden, for consistent product quality. A wholesale outlet in Addis Ababa enables different institutions and retailers to purchase stoves from Makobu wholesale. These include the UNHCR for its refugee camps, and distributors within Ethiopia and in neighbouring countries. Gaia Association purchases stoves from the wholesale market, whilst households purchase stoves from retailers and local distributors. Stoves purchased by Gaia Association will be used for subsidised sales. Gaia is also currently pursuing enlisting carbon finance to improve the stove economics [Practical Action Consulting, 2009].

According to Debebe & Lambe [2008], the CC stove is established technology, thoroughly tested and highly efficient. It is an adaptation of leading alcohol stoves which have been used in niche applications in the developed world. Being non-pressurised, the stove has a special fibre-filled fuel canister that holds ethanol adsorbed in the canister's ceramic fibre so that it cannot spill, allowing it to evaporate from the canister into a combustion chimney where the alcohol burns as a gas – like LPG. Because of the low surface tension of alcohol, it adheres to the mineral fibre in the canister, but because of its excellent evaporative characteristics, it evaporates readily from the surface of the mineral mass into the heat of a flame. Since it is non-pressurised, there is no risk of explosion. The burner chimney of the stove mixes the alcohol fuel as it volatises from the canister with the right amount of air to produce a hot and well focussed flame. Its flame in the burner is adjustable, allowing economic fuel use. The flame regulator is the only moving part of the stove and is easily repaired if broken. Constructed entirely from stainless steel, the stove is durable with an estimated 10-year life. It is currently available either with one or two burners; each burner provides 1.5kW of heat output and has its own fuel canister that holds 1.2 litres of fuel sufficient for 4.5 hours of cooking. One of the breakthroughs with this stove, in addition to safety, is its performance. It has excellent heating power, equivalent to an LPG stove, and it has excellent turn-down capability to conserve fuel and simmer food. Moreover, it has an efficiency rating of 50-55%, which is the effective peak efficiency for any stove on the market today. The stove has been redesigned for the Ethiopian market to be more cheaply manufactured, to be stronger, to hold larger pots, and to hold round bottomed pots.

On policy, the Ethiopian government is targeting the domestic market for all ethanol produced in the country. Gaia Association works closely with the government and the sugar agency to ensure a reliable supply chain for the fuel. Ethanol supply at a reasonable price as well as realistic taxes on raw materials are an essential part of the enabling environment for the ethanol stove market in Ethiopia. Current ethanol production (8 million litres) is unlikely to meet national household market demand, but there is a programme to expand ethanol production and construction of new distilleries. Annual ethanol production is projected to be about 129 million litres by 2013 [Practical Action Consulting, 2009].

5 ENERGY CROPS AGRONOMICS: JATROPHA

Current information on many energy crops such as Jatropha, Pongamia, etc is anecdotal at best and it is not enough for investors as well as policy makers to make informed decisions about land use and the promotion of a biodiesel agro-industry. It is critical to fill this information gap by providing science based public information that can be used by decision makers. For instance it is very important to identify and promote improved Jatropha varieties and corresponding seed and propagation technologies along with the best agronomic management practices that will allow for the development and establishment of successful Jatropha agro-systems.

5.1 Botanical description of Jatropha curcas L.

JCL or physic nut is a small tree or large shrub, up to 5–7m tall, belonging to the Euphorbiaceae family, and grows for more than 50 years. The plant has its native distributional range in South and Central America, although nowadays it has a pantropical distribution with distinct JCL seed provenances [Henning, 2007]. The plant develops a deep taproot and initially four shallow lateral roots [Heller, 1996]. The taproot may stabilize the soil against landslides while the shallow roots are capable of preventing and controlling soil erosion caused by wind or water, but this potential has not been investigated scientifically. Normally JCL flowers only once a year during the rainy season, but in permanently humid regions or under irrigated conditions JCL flowers almost throughout the year [Heller, 1996]. The blackish seeds of most provenances contain toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins and phytates, to such levels that the seeds, oil and seed cake are not edible without detoxification.

5.2 Jatropha cultivation

Cultivation of JCL is the first production step towards biodiesel production. The main inputs are land area, labour and expertise in plantation establishment and management practices including the production and use of all machines, infrastructure, energy and agrochemicals.

5.3 Site requirements

JCL's high ecological adaptability allows it to grow in a wide range of conditions. As a succulent that sheds its leaves during the dry season, JCL is well adapted to semi-arid conditions, although more humid environmental conditions are shown to result in better crop performance. The documented seed provenances show average temperatures between 20 and 28^{o}C, but its occurrence has been observed in a rainfall range between 250 and 3000mm [Heller, 1996; Makkar *et al.* 1997]. JCL can tolerate high-temperature extremes, but generally fears frost, which causes immediate damage. It can flourish for an altitude range from sea level up to 1800m [Foidl *et al.* 1996]. The plant is not sensitive to day length. JCL can grow in a wide range of soils. Well-drained sandy or gravelly soils with good aeration are preferred. In heavy soils, root formation will be hampered [Heller, 1996]. JCL should never be planted on soils with risk of even ephemeral waterlogging, such as Vertisols or other heavy clay soils [Biswas *et al.* 2006]. Soil depth should be at least 45cm and surface slope should not exceed 30^o. JCL has low nutritional requirements, but the soil pH should not exceed 9 and on very acidic soils JCL might require some Ca and Mg fertilization [Biswas *et al.* 2006]. JCL is well adapted to marginal soils with low nutrient content, but in order to support a high biomass production the crop shows a high demand for nitrogen and phosphorus fertilization [Heller, 1996; Foidl *et al.* 1996].

Mycorrhiza has been shown to assist with the uptake of phosphorus and micro-elements in the root system. Mycorrhiza-inoculated JCL showed a 30% increase in both biomass and seed production 7 months after plantation of 1-year-old saplings.

6 PLANTATION MANAGEMENT AND OPERATIONS

6.1 Jatropha propagation and plantation establishment

JCL is easily propagated by generative (direct seeding or pre-cultivated seedlings) and vegetative (direct planting of cuttings) methods. The crop shows high initial establishment success and survival. For quick establishment of living fences and plantations for erosion control, direct planting of cuttings is considered easier, although JCL plants propagated from cuttings do not develop a taproot [Heller, 1996]. The plants only develop thin roots unable to grow deep in the soil, which makes the plants more susceptible to up rooting by wind. In agroforestry and intercropping systems, direct seeding should be preferred over pre-cultivated JCL plants, as the taproot of directly seeded plants is believed to penetrate in deeper soil layers where it can assess extra nutrient resources and where it competes less with the roots of the other crops. If early seed yields are to be achieved, direct planting of stakes can be used as well [Heller, 1996].

Recommendations on vegetative propagation vary. Cuttings of 25–30cm length from 1-year-old branches or longer cuttings upto120cm are among the options. Kaushik and Kumar [2004] report that the survival percentage depends on the origin of the source material (top, middle or base of the branch) as well as the length and diameter combination of the cutting. Their study showed a survival percentage of 42% when the tops of the branches were used as cuttings, while cuttings from the middle (72%) and base (88%) showed significantly better survival results. The product of the length and diameter dimensions of the used cuttings had a positive correlation on the survival percentage as well. The longer and larger a cutting, the higher its survival rate. Cuttings can be planted directly in the field or in nursery beds or polyethylene bags for first root development [Heller, 1996; Kaushik & Kumar, 2004]. They have to be placed 10–20cm into the soil depending on their length and diameter. Planting of cuttings is best done in the rainy season.

Using generative propagation, direct seed sowing is recommended at the beginning of the rainy season, after the first rains when soil is wet, because it helps to develop a healthy taproot system. Seedlings can be pre-cultivated in polythene bags or tubes or in seedbeds under nursery conditions. The use of plastic bags or tubes is observed to induce root node formation and spin growth. In the nursery, seeds should be sown 3 months before the rainy season in a soil with a high concentration of organic material and should be well watered [Henning, 2000]. Pre-soaked seeds (24 hours in cold water) germinate in 7–8 days in hot humid environments whereas the process continues for 10–15 days. A study on the germination enhancement of JCL seeds, Brahmam [2007], showed best results for pre-soaking in cow-dung slurry for 12 hours. Nicking yields similar germination rates.

At the onset of rains, JCL seedlings can be planted. Planting densities of 2,500 plants, 1,600 or 1,111 plants per ha are common practice [Heller, 1996]. Kaushik and Kumar [2004] propose to use wider spacing patterns (4x2 and 4x3m^2) and agroforestry systems (spacing 5x2 and 6x6m^2) to optimize the yield of individual JCL plants. In 2.5-year-old plantations it was observed that with increasing spacing, seed yield per tree increased significantly, while the seed yield per ha decreased. The recommended spacing in hedge rows for soil conservation is 15–25cm within and between (in case of double fence) rows (4,000–6,700 plants per km). Henning [2007], suggests that the optimal tree density is close to 1300 plants per ha. Higher densities for grown-up plants would not allow people to pass between the plants to harvest the fruits.

Field preparation for plantations mainly consists of land clearing and preparation of the planting pits for the pre-cultivated plants. Although planting can be done without any clearing, for oil production purposes it is advisable to clear the land at least partially. Tall trees can be left, but Shrubs and bushes that cover the soil should be cut. Ploughing the field belongs to the possibilities as well. After clearing, planting pits should be dug prior to the rainy season. For good establishment the pits are best refilled with a mixture of the local soil, sand, organic matter such as compost and/or artificial fertilizer. The best moment for planting is the warm season-if watering can be provided - or at the onset of the rains. Gour [2006] has observed that seedlings require irrigation, especially during the first 2–3 months after planting, depending on local soil and climatic conditions.

6.2 Tending practice of Jatropha plantations

Weeding

According to Tigere *et al.* [2006] weeding JCL is not normally done as the shrub's fast growth quickly smothers weeds. However, several recent studies such as Gour [2006], and Kaushik & Kumar [2004] recommended weeding and pruning of JCL plants. Regular weeding operations should free the field from competitive weeds. Uprooted weeds can be left on the field as mulch. Pruning and canopy management is presented as an important crop architectural intervention, which is believed to help the production of more branches and to stimulate abundant and healthy inflorescence, thus eventually enhancing good fruit setting and seed yield. At the age of 6 months it is useful to pinch off the terminal shoots in order to induce lateral branching. Studies reveal that pruning the main branch at 30–45cm height—depending on the growth rate-is ideal [Gour, 2006]. At the end of the first year, the secondary and tertiary branches should be pinched or pruned to induce more branches. During the second year each side branch should be pruned up to two-thirds of the top portion, retaining one-third of the branches on the plant [Gour, 2006]; Kaushik & Kumar, 2004]. Pruning should be done in the dry or winter period after the trees have shed their leaves. This will result in a lower and wider tree shape, induce earlier seed production and facilitate manual harvesting. Once every 10 years, the entire plant has to be cut low, leaving a stump of 45 cm. The re-growth will be quick and the trees will start yielding again within about 1 year. This intervention will induce new growth and help to stabilize the yield [Gour, 2006]. Besides trimming hedgerows and pruning plantations annually, periodic thinning of plantations is proposed as well. Starting from 1600 seedlings per hectare, stand density should be thinned to 400–500 trees per hectare in the final mature stand.

Fertilisation and irrigation

It is clear that optimal fertilization and irrigation application can increase the seed and oil yield. However, permanent humid situations and/or situations with high irrigation and fertilizer application can induce high biomass but low seed production. The input levels to optimize the harvest index in given conditions are yet to be quantified. No quantitative data on water need, water productivity and water use efficiency of JCL are available at present. In general application of super phosphate or NPK fertilizer is reported to increase the yield. The optimum application levels of inorganic N and P fertilizers are observed to be variable according to the age of the plantation. On degraded sites JCL plants are found to respond better to organic manure than to mineral fertilizers. Jongschaap *et al.* [2007] estimated that harvesting the one tonne of seeds per hectare results in a net removal of 14.3–34.3 kg N, 0.7–7.0 kg P and 14.3–31.6 kg/kha. Hence fertilization (artificial or organic) at least has to compensate this.

Pesticides

A popular belief is that JCL is not prone to pests and diseases in such extent to cause economic damage. However, in continuous JCL monocultures in India economic damage has already been observed [Shanker & Dhyani, 2006]. Heller [1996] identifies numerous pests, diseases and damaging insects observed on JCL. It is believed that JCL can transmit the cassava super elongation disease and is a possible host for African Cassava Mosaic Virus. Other bugs identified include the scutellarid bug *Scutellera nobilis,* the inflorescence and capsule-borer *Pempelia morosalis*, the blister miner *Stomphastis (Acrocercops) thraustica*, the semi-looper *Achaea janata* and the flower beetle *Oxycetonia versicolor* [Shanker & Dhyani, 2006]. Achten etal. 2007 believes the susceptibility of JCL for pest and diseases depends on the management intensity. Regular irrigation and fertilizer application is expected to enhance these pest and disease infestations in commercial monocultures.

6.3 Seed yield

For best oil yields, the seeds should be harvested at maturity. Maturity is reached 90 days after flowering. Mature JCL seed yield per ha per year is still not scientifically determined, since systematic yield monitoring only started recently. Reported figures vary over a wide range (0.4–12 t/ha/yr) and are not coherent, mainly because of incorrect extrapolation of annual yields of individual trees to per ha per yr yields [Heller, 1996; Jongschaap *et al.* 2007]. Table 2 shows the range of seed yield from several observations around the world complied by Plant.a.Bio Agrotecnologia Ltda. of Brazil. At present the effect of spacing, canopy management and crown form and surface on the yield is not known, making it impossible to make such extrapolation [Achten *et al.* 2008].

Yield depends on site characteristics (rainfall, soil type and soil fertility), genetics, plant age and management (propagation method, spacing, pruning, fertilizing, irrigation, etc.) [Heller, 1996; Gour, 2006]. Information on these yield influencing variables was generally not reported alongside. JCL has not yet undergone a careful breeding program with systematic selection and improvement of suitable germplasm, which is why it can still be considered a wild plant that exhibits great variability in productivity between individuals [Achten *et al.* 2007; Jongschaap *et al.* 2007]. Annual seed production can range from about 0.2 kg - 2 kg per plant. For semi-arid areas and cultural wasteland dry seed production of 2–3 t/ha/yr is achievable [Heller, 1996]. When good sites (good soil and average annual rainfall of 900-1200mm) are claimed and/or optimal management practice is used, 5 t dry/ha/yr can be achieved [Foidl, 1996]. Jongschaap *et al.* [2007] gives a potential yield range of 1.5–7.8 t dry seed/ha/yr.

Table 2: Jatropha seed yields

Country	Source	Seed yield (tonnes/ha)	Age (yrs)
Indonesia	a.	4-5	5
	b.	4-6	5
India	a.	5	5
	b.	4	4
Ghana		7-8	5
Philippines		3.5-5	5
Nicaragua		4-5	4
Costa Rica		4.8	5
Peru	a.	6.25	5
	b.	0.8	1
	c.	2.5	2
Brazil	a.	4	3
	b.	6	4
Global	a.	6-8	5
	b.	12.5	5
Potential		12-15	5

Source: Plant.a.Bio [2009]

Harvesting

JCL fruits do not mature all at the same moment and as such the fruits have to be harvested manually at regular intervals, making this step very labour intensive [Heller, 1996]. The moment and length of harvest period is likely to vary according to the seasonal conditions of the locality. In semi-arid regions the harvest is spread over a period of 2 months, which implies daily or weekly harvests. In permanent humid situations weekly harvest can be necessary all year through. Separation of the seeds and husks can be done manually or mechanically [Gour, 2006].

7 BIODIESEL PROCESSING SCHEMES

This section reviews the best practice of various processes available for producing marketable grade biofuels from oil-seed crop feedstock. While a wide variety of approaches and feedstock exist for producing ethanol, there is a much narrower range for biodiesel. Straight Vegetable Oils or Pure Plant Oils are an intermediate product in the biodiesel production process and thus considered part of the biodiesel production chain.

Biodiesel can be produced from a variety of lipid feedstocks, catalysts and alcohols using several possible conversion processes, making it difficult to define biodiesel in any singular way. Over the last 100 years of biodiesel research and manufacture, refining processes have matured, new feedstock sources have been tested and engine technology has been continuously optimized. Today, biodiesel has much stricter definitions in the form of quality standards, established to gain wider acceptance from engine manufacturers, distributors, retailers and end users. In 2001, the US established the ASTM biodiesel standard D 6751 which regulates 14 fuel properties including flash point, water content, cetane and cloud point. Similarly, the European Union passed the biodiesel standard EN 14214 in 2003 [Johnston, 2006].

The conversion of lipids into biodiesel requires several simple processes which differ depending on the feedstocks and type of transesterification method used. First, the oil from the nut or seed bearing plant must be extracted and processed/purified. Then, transesterifying the oil with an alcohol in the presence of a catalyst will yield biodiesel and glycerol.

7.1 Feedstocks for biodiesel production

Various feedstocks available in different forms are used in the production of biodiesel. Different feedstock types are characterized by different properties. For instance, the oil saturation and the fatty acid content of different oilseed species vary considerably and these affect the yield and quality of the biodiesel produced. Selection of the right kind and quality of raw materials is very essential in achieving good yields and obtaining a product of the right quality and right price. Feedstock selection for biodiesel production depends on the geographical region, climatic conditions, availability, cost and competition for other applications (e.g. food, feed or other industrial and commercial applications). Potential feedstocks for commercial biodiesel production include a variety of oils and fats, i.e.:

- Animal fats: edible tallow, inedible tallow, and all the other variations of tallow, lard, choice white grease, yellow grease, poultry fats and fish oils.
- Vegetable oils: jatropha, soy, palm, corn, canola, sunflower, rapeseed, cottonseed
- Recycled greases: used cooking oils and restaurant frying oils.
- Other oils, fats and recycled oils such as mustard, coconut, peanut, olive, sesame, and safflower oils, trap greases, and even oils produced from algae, fungi, bacteria, moulds, and yeast.

Although any animal or plant lipid should be a ready substrate for the production of biodiesel, whether a particular potential feedstock is actually adopted for commercial fuel production will depend on several factors such as supply, cost, storage properties, levels of free fatty acids, water and other undesirable impurities and engine performance characteristics. Selection of oilseed feedstock should take into consideration such aspects some of which details are provided below:

Oil saturation

Compared to the chemistry of diesel fuel, which contains hundreds of compounds, the chemistry of different fats and oils typically used for biodiesel are very similar. Each fat or oil molecule is made up of a glycerine backbone of three carbons, and on each of these carbons is attached a long chain fatty acid. Most fats and oils contain 10 common types of fatty acids and some of these fatty acid chains are saturated, while others are monounsaturated or polyunsaturated (see Figure 3). The differing levels of saturation can affect some of the biodiesel fuel properties and is the key determinant differentiating the various feedstocks. A "perfect" biodiesel would be made only from monounsaturated fatty acids.

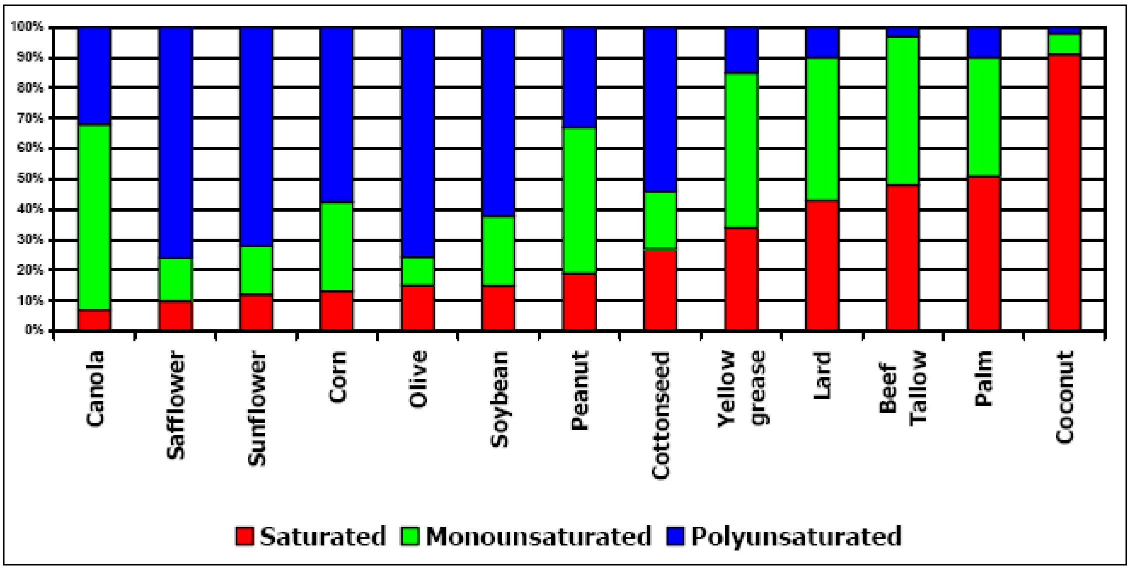


Figure 3: Fatty acids composition of various biodiesel feedstocks
Source: Tyson, 2004

The level of saturation of fatty acids in biodiesel feedstocks is important when considering potential applications because of the impact of composition on the fuel properties as well as emissions. These properties can include cetane number, cold flow, bulk modulus (compressibility), and stability. Tests have shown that differing biodiesel properties can also lead to different levels of NO_x emissions from compression ignition engines, although this does not appear to be the case with other emissions (HC, CO, PM) or with other applications such as open flame combustion in boilers.

Table 3: Fuel Properties as a Function of Fuel Composition in Diesel Engines

	Saturated	Monounsaturated	Polyunsaturated
Fatty acid[1]	12:0, 14:0, 16:0, 18:0, 20:0, 22:0	16:1, 18:1, 20:1, 22:1	18:2, 18:3
Cetane Number	High	Medium	Low
Cloud Point	High	Medium	Low
Stability	High	Medium	Low
NOx Emissions	Reduction	Slight increase	Large increase

[1] First number shows number of carbons in fatty acid chain: second number is the level of saturation or unsaturation- 0 for saturated, 1 for monounsaturated, and 2 or 3 for polyunsaturated.
Source: Tyson, 2006

Free Fatty Acids (FFA)

This is the amount of free fatty acids contained in the product. Fats and oils are compounds containing three fatty acids each chemically connected to oxygen on a glycerine molecule, called triglycerides. Free fatty acids are those structures that are no longer connected to the glycerine. They are a degradation product and a measure of the quality of the fat. A high quality fat has a low FFA level.

Moisture, Insolubles, Unsaponifiables (MID)

MID is a measure of the remaining compounds in the oil that are not fatty acids or triglycerides. Generally, the lower the MID level, the higher the quality of the oil and the easier it is to process it into biodiesel. It is considered a measure of quality [Méndez, 2006].

Suspended solids (SS)

SS is defined as the dry weight percent of hexane insoluble materials retained on an lOO-micron filter. The lower the amount of suspended solids, the better the quality [Méndez, 2006].

Policy driven choices

Governmental decisions can affect choice of feedstock, e.g. a governmental subsidy programme favouring one feedstock could seriously affect feedstock choices. Thus, early support programmes in the United States favoured the use of refined soybean oil as a feedstock. Conversely, Brazil is making efforts to foster a castor oil-based biodiesel industry, despite being the world’s second largest producer of soybeans because it is felt that adequate markets for soy oil exist, whereas the sale of castor oil into the biodiesel market would provide income to impoverished regions of the country where soy cannot be grown [Knothe *et al.* 2005].

Therefore, characteristics such as oil saturation, the free fatty acids, moisture and suspended solids are important characteristics to be taken into account in the selection of the oilseed. A typical value for soy seeds is 2.5% on FFA and 0.25 on %MIU. However, government policy also plays an instrumental role in feedstock selection in many countries.

Biodiesel production involves three major steps that begin with processing of raw feedstocks (seeds) to the finished products (biodiesel and glycerol by-product). These include:

(a) extraction of oil from raw feedstock,
(b) refining of the oil (to produce straight vegetable oil) and
(c) esterification of the oil to obtain the biodiesel.

Two fundamental production pathways are practiced depending on the scale of the operation, industrial or small scale:

- Industrial production in centralized production in large industrial plants
- Small scale pressing in decentralized cold pressing facilities directly on farms or in cooperatives.

The procedures for oil extraction and refining are based mainly on those described by Achten, *et al.* [2008] and Rutz and Janssen [2008].

7.2 Oil extraction

Extracting oil from oil seeds is as old as mankind, but the procedures and technologies have evolved. In this second step of the production chain for biodiesel, the oil contained in the seeds has to be expelled or extracted. In extracting oils from oilseeds, the primary goal is to disrupt the cell walls, thereby liberating as much oil as possible [Johnston, 2006].

Generally oil extraction from oilseed crops is similar with minor variations. For some oilseeds, additional process steps might be necessary while no modifications may be necessary for others. For example some large seeds such as sunflower seeds, have to be peeled, while for others peeling is not necessary. Typically, seeds are pre-treated, if necessary, for example by steaming followed by extraction using various extraction techniques. Rape seeds have to be dried first from moisture content of about 15 % to 9 %, but only if it is to be stored for more than ten days. Subsequently, the rape seeds are cleaned [Takavarasha *etal.* 2006]. In the oil extraction process of palm oil, a large amount of steam has been used in order to soften the palm fruitlets, whereas for other oilseeds such as rapeseed only a mechanical pressing process is required. Two main oil extraction methods can be identified:

(i) mechanical extraction and
(ii) chemical (solvent) extraction.

Mechanical extraction processes are generally inefficient and used at small scale applications; chemical extraction is more efficient but viable only at large scale. Small decentralized expellers typically have throughputs ranging from 30 to 50 kg/hr to 1000 kg/hr. In these expellers the oil is normally extracted by cold pressing, the maximum oil that can removed from the oil seeds by this process is about 90%, balance of the oil is retained by the oil cake; whereas solvent extraction can achieve efficiencies of up to 98% [Takavarasha *et al.* 2006]. For mechanical expellers the reduction in oil output is partly offset by an enhanced cake value particularly if the oil is edible oil as it is sold as a protein rich animal feed.

The following description is based on using Jatropha Curcas L. as a feedstock in oil production. Prior to oil extraction the JCL seeds have to be dried. Seed can be dried in an oven (105°C) or sundried (for about 3 weeks). Mechanical expellers or presses can be fed with either whole seeds or kernels or a mix of both, but common practice is to use whole seeds. For chemical extraction only ground JCL kernels are used as feed. The shells can be used directly as a combustible by-product or as gasification feedstock.

7.2.1 Mechanical expellers

Physical oil extraction technology has been in existence since time immemorial and involves mechanical presses or expellers. Mechanical extraction of the oil from seeds mainly employs either a manual ram press (such as the Yenga or Bielenberg ram press) or an engine driven screw press (such as the Sundhara press). Generally the different mechanical extraction methods can be classified into the following:

- Hand operated mechanical presses
- Hand operated hydraulic presses
- Animal operated grinding mills cum presses
- Electric powered grinding mills cum press
- Electrically powered oil expellers [Takavarasha *et al.* 2006].

Traditionally, screw presses have been used, but nowadays hydraulic presses are able to achieve higher efficiencies. In small scale cold pressing facilities, cleaned oil seeds are mechanically pressed at maximum temperatures of 40 °C. Suspended solids are removed by filtration or sedimentation. As a co-product, the press cake is left with a remaining oil content of usually over 10 %, which is used as a protein-rich fodder. Furthermore, the co-product could be directly used for feeding the animals [Rutz & Janssen, 2008]. Until large scale industrial oil extraction plants are in place, many African communities can depend on small scale cold pressing facilities for their oil extraction. This will have an added advantage of social cohesion among the farmers.

According to Henning [2000], the engine driven screw presses extract 75–80% of the available oil, while the manual ram presses only achieve 60–65%. Other studies such as Beerens [2007] also give oil extraction efficiencies within the same range, although the efficiency range of engine driven screw presses is broader 70–80%. This broader range corresponds to the fact that seeds can be subjected to a different number of extractions through the expeller. Up to three passes is common practice. Pre-treatment of the seeds, like cooking, can increase the oil yield of screw pressing up to 89% after single pass and 91% after dual pass [Beerens, 2007].

7.2.2 *Chemical extraction*

Most large-scale vegetable oil processing facilities, however, use hexane in a chemical extraction for its higher rate of recovery. Table 4summarizes the reaction temperature, reaction pH, time consumption and oil yield of different chemical extraction methods tested on JCL. The *n*-hexane method is the most common and results in the highest oil yield, but also takes most time. In aqueous enzymatic oil extraction the use of alkaline protease gave the best results for both available studies. Furthermore, ultrasonication pretreatment has been shown to be a useful step in aqueous oil extraction. However, according to Adriaans [2006] solvent extraction is only economical at a large-scale production of more than 50 tonnes of biodiesel per day. Furthermore conventional *n*-hexane solvent extraction is not recommended because of environmental impacts (generation of wastewater, higher energy consumption and higher emissions of volatile organic compounds) and human health impacts (working with hazardous and inflammable chemicals). Using aqueous enzymatic oil extractions greatly reduces these problems as do the use of supercritical solvents (mainly supercritical CO_2) or bio-renewable solvents as bio-ethanol and isopropyl alcohol [Adriaans, 2006]. Although the new generation *n*-hexane extraction units are very efficient and produce far less environmental burdens than the older units, further research on these alternative solvents is recommended as on their commercial viability.

Table 4: Reported oil yields (% of contained oil) for different chemical extraction methods and different reaction parameters

Extraction method	Reaction temperature (°C)	Reaction pH	Time consumption (h)	Oil yield (%)
n-hexane oil extraction (Soxhelt apparatus) 1st acetone 2nd- *n*-hexane	- -	- -	24 48	95-99
Aqueous oil extraction (AOE)	-	-	2	38
	50	9	6	38
AOE with 10 min of utrasonication as pretreatment	50	9	6	67
Aqueous enzymatic oil extraction (AEOE) (hemicellulase or cellulose)	60	4.5	2	73
AEOE (alkaline protease)	60	7	2	86
	50	9	6	64
AEOE (alkaline protease) with 5 min of utrasonication as pretreatment	50	9	6	74
Three phase partitioning	25	9	2	97

Source: Achten *et al.* [2007]

In many developing countries where the seed production is highly decentralized and the quantity of oil seeds to be crushed relatively small, mechanical presses with low capital investment may be a viable option. In case the need arises these extraction units can eventually become an ancillary to the larger solvent plants as suppliers of raw materials i.e. crushed cake. For large-scale and efficient extraction of oil from oilseeds solvent extraction is the most commonly used process. For relatively smaller oil extraction units, batch process while for large scale units continuous solvent extraction unit is the preferred option.

7.3 Palm oil extraction

Extraction of palm oil by milling is an established process which differs from the typical oilseed extraction process. Fresh palm oil fruit bunches bought from farmers are supplied into an oil milling factory. Each bunch is weighed after which it is conveyed through steam where the fruitlet bunch stems are softened. The free-fatty acid content is also reduced in this process. Each fresh fruit bunch (FFB) which is supplied to the palm oil refinery has 90% of ripe fruitlets providing 22% of crude palm oil (CPO) and 2.5% of kernel palm oil (KPO) measured by weight. The remaining 75.5% consists of empty bunches, water, shells, and fibres [Thamsiriroj, 2007].

Following steaming, the fruitlet bunch is lifted up by pulley to the plucking machine which removes the bunch stems from the fruitlets. In this process, all fruitlets are eventually separated from bunches.

The palm fruits are then conveyed by a screw conveyer to a splitting machine where the palm fruit is divided into its shell and mesocarp. Both shell and mesocarp are sent to the pressing machine. The process provides fibreshell and a combination of oil, water and fibre as outputs. This combination is passed to the sieves and fractioning system, which separate oil from its residue and water. The residue can be used directly as fertilizer, while the water must be treated in a water treatment plant before utilising as fertilizer. The oil is passed through a purification process to wash out sand and fine material. Moisture is also removed in a vacuum. After these processes, pure palm oil or so-called crude palm oil (CPO) will be filled in a container and sold to a refining factory for further fractional processing.

The fibres and shells received from the pressing machine are separated from each other by a scraping process. The shells are contained in a silo and allowed to develop heat so as to maintain their qualities. The shells are then taken for chipping to separate inside hard kernel (seed) from the empty shell. The hard kernel is heated and kept in a silo where it is ready for the oil extraction process. Oil extracted from the kernel, so-called kernel palm oil (KPO), is used extensively in butter, margarine, and soap production. The empty shell is crushed into small pieces and kept in a storehouse for selling as a mixture for animal feed. Residue from the hard kernel remaining after the oil extraction process is sold as fertilizer.

Fibres are burned to heat the steam boiler which generates electricity to supply all operations in the factory. Exhaust steam is circulated to soften fruitlet bunches at the beginning of the process.

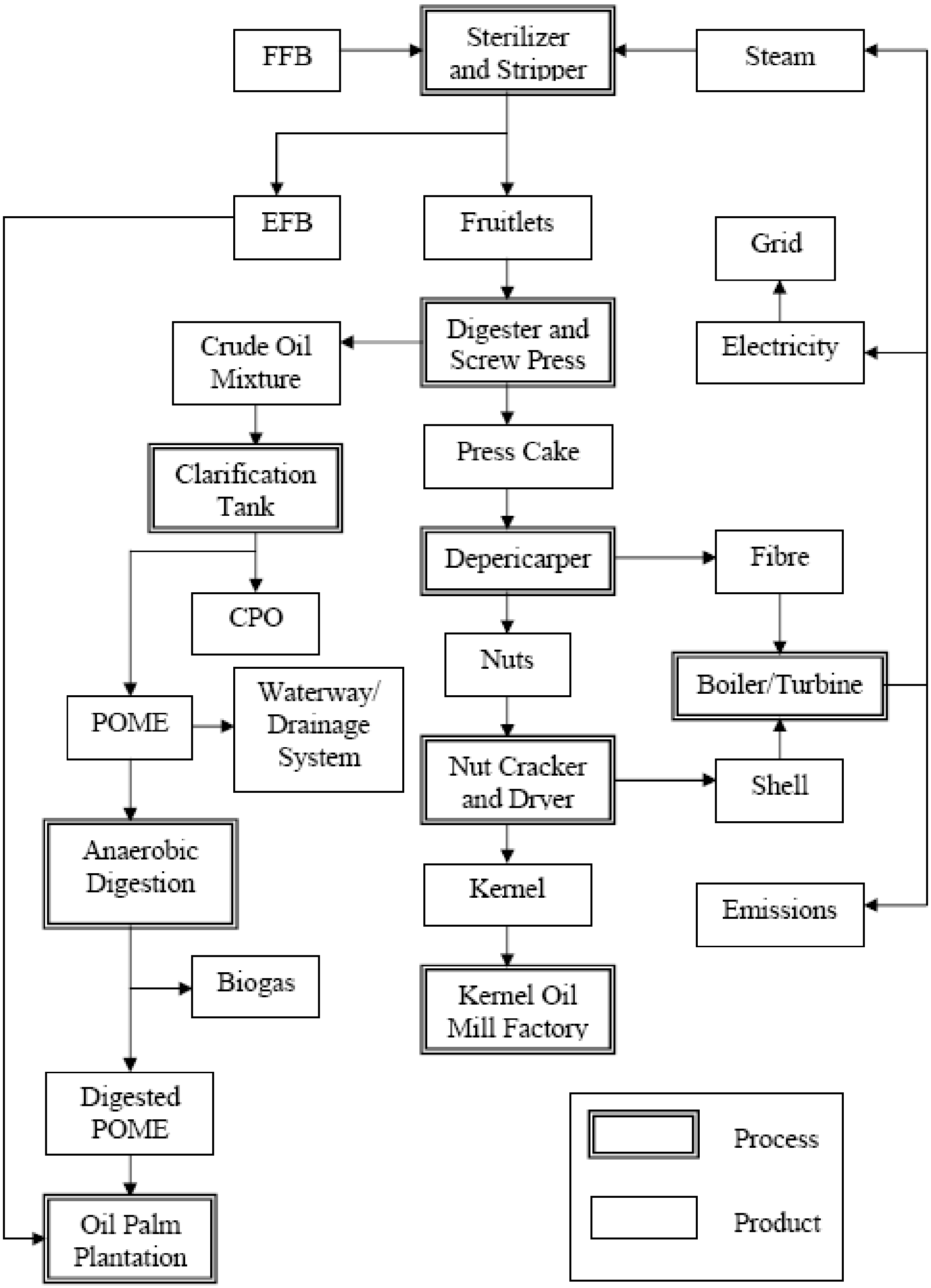


Figure 4: Palm oil milling
Source: Yusoff & Hansen [2007]

7.4 Oil refining

The refining process is an important treatment of creating PPO and of preparing vegetable oil for the transesterification process of biodiesel. It is important in order to remove undesirable substances, such as phosphatides, free fatty acids, waxes, tocopherols and colorants. These substances can alter oil storage life and hamper further processing. During this first refining step the oil mass (4 to 8 %) and the solvent contents are reduced. Since the refining process depends on the vegetable oil quality, the refining steps depend on the feedstock source. There also exist alternatives of refining and some refining steps are merging.

Filtration

After oil has been expelled the minimum treatment it needs to undergo is the process of filtration. The filtration is typically carried out using filter presses. The expelled SVO is pumped at sufficient pressure to a filter press or a number of filter presses. In the filter press the filter cloth removes the suspended solid impurities. A filter aid may be used to facilitate the filtration of oil [Takavarasha *et al.* 2006].

Degumming

After filtration, the next most important oil purification step is the removal of phosphatides, also known as degumming process. This is necessary as phosphatides make the oil become turbid during storage and as they promote the accumulation of water. Phosphatides can be removed by two different ways: water degumming and acid degumming. Water soluble phosphatides can be removed by water degumming. In this case water is added to the oil at 60-90°C and the mixture is separated by centrifugal separation of the water phase and the oil phase. Acid degumming is applied to phosphatides which cannot be hydrated. Acid substances like citric or phosphoric acid are added. Benefits can also be derived from using small amounts of methanol in this process step or the application of enzymatic hydrolysis to effectively remove both soluble and insoluble phosphatides [Mittelbach and Remschmidt, 2004].

Deacidification

The third refining step is the deacidification. It is an important step for edible oils as the development of rancid flavours of free fatty acids (FFA) is prevented. The content of these FFA's in unrefined pure oil is between 0.3 and 6 %. In this step also phenol, oxidized fatty compounds, heavy metals and phosphatides are removed. The purification of all these substances is not only important to edible oils, but also to fuel production as these compounds alter the storage life and influence transesterification in the biodiesel process. Several methods of deacidification are in operation:

- Neutralization with alkali: This is the most applied method. FFA's are saponified with alkaline solutions and the resulting soap is separated.
- Distillation: For this alternative more energy is needed.
- Deacidification by esterification: This is done by esterification of FFA's with Glycerine
- Deacidification and extraction of colorants and odours with various solvents: (e.g.,. ethanol, furfural, propane)

Bleaching

In the fourth bleaching step, colorants are removed. This process enhances storage life of the biofuel. Adsorbing substances are mainly used for bleaching; examples include bleaching earth, silica gel or activated carbon. Oxygen, ozone, hydrogen peroxide and heat (200°C) can also be used for bleaching.

Deodorisation and dehydration

In the deodorization step odorous substances (ketone, aldehyde) are removed by steam distillation. Finally a dehydration step has to be conducted, as traces of water may decrease conversion in the transesterification process of biodiesel production. The removal of water is either accomplished by distillation under reduced pressure or by passing a stream of nitrogen through the fatty material (Mittelbach and Remschmidt, 2004).

7.5 Transesterification

Biodiesel comprises of non-alkyl esters of chain fatty acids derived from vegetable oil or animal fats. It is also commonly referred to as Fatty Acid Methyl Ester (FAME) – if produced using methanol or Fatty Acid Ethyl Ester (FAEE) if produced using ethanol in the esterification process (although the latter is limited). In Europe, biodiesel produced from rapeseed oil is referred to as Rape Methyl Ester (RME). FAME can be produced by a variety of esterification technologies. The production of biodiesel, or methyl esters, by esterification is a well-known chemical process that has been used for decades in the soap and detergent industry.

Currently, there are three basic chemical routes to produce methyl esters from oils and fats:

- Base catalyzed transesterification of oil with methanol.
- Direct acid catalyzed esterification of oil with methanol.
- Conversion of the oil to fatty acids, and then to methyl esters with acid catalysis.
- Catalyst free supercritical process

According to Méndez [2007] selection of the chemical routes and the technology process is based on the following aspects:

- Scale (Size of Plant)
- Batch vs. Continuous Technology
- Capital and Operating Cost
- Product Yields and Feedstock Quality.

Most of the biodiesel producers use the base-catalyzed reaction called transesterification or alcoholysis (or methanolysis if methanol is used) [Meher *et al.* 2004] Batch processing is also commonly employed. This is mainly for economical and operational reasons whose justification is based on the fact that it is easier to handle variations in raw material quality in a discontinuous process.

A conventional transesterification batch process using methanol as a reactant and sodium hydroxide as a catalyst is illustrated in the study. The production process consists of solvent preparation, reaction stage, glycerol separation, washing stage, and finishing stage.

7.5.1 Solvent preparation

Because methanol is cheap and available, it is generally used as an alcohol in the transesterification process to generate methyl ester. The sodium hydroxide (NAOH) is used as a catalyst for the same reasons. It also has the advantage of accelerating the chemical reaction. Methanol must contain water at less than 1%. The solvent is prepared by mixing NAOH in methanol with a ratio of 2.5-5:100 parts by weight, varying the NAOH depending on level of free-fatty acid in oil. If the concentration is high, the amount of NAOH is also high [Thamsiriroj, 2007].

7.5.2 Reaction stage

Following pretreatment, the vegetable oil is cooled until the temperature is close to 80^{o}C. The ready-mixed solvent is added to the oil slowly. Ratio between oil and solvent is 5 to 1. The mixture is stirred for about 5 minutes to allow the chemical reaction to spread through the mixture. The rate of stirring is at about 500 rpm. The reaction occurs rapidly when the mixture is cooled down to about 65^{o}C. As a result, methyl ester is produced with glycerol as a by-product. The reaction can occur backwards; stirring is stopped to allow separation. Glycerol which has a higher density (about 1.26 g/ml) will naturally separate from methyl ester and settle at the bottom. The reaction will continue to occur slowly and almost 95% of the oil will have reached after 3-4 hours.

Barnwal and Sharma [2004] identified five key process variables that influence the transesterification reaction as follows:

- Reaction temperature
- Ratio of alcohol to vegetable oil
- Catalyst
- Mixing intensity
- Purity of reactants.

Reaction temperature

The rate of reaction is strongly influenced by the reaction temperature. However, the reaction is conducted close to the boiling point of methanol (60–70 8C) at atmospheric pressure for a given time. Such mild reaction conditions require the removal of free fatty acids from the oil by pretreatment. Therefore, degummed and deacidified oil is used as feedstock. Pretreatment is not required if the reaction is carried out under high pressure

(9000 kPa) and high temperature (240^{o}C), where simultaneous esterification and transesterification take place with maximum yield obtained at temperatures ranging from 60 to 80oC at a molar ratio of 6:1.

Ratio of alcohol to oil

Another important variable is the molar ratio of alcohol to vegetable oil. The transesterification reaction requires 3 mol of alcohol per mole of triglyceride to give 3 mol of fatty esters and 1 mol of glycerol. In order to shift the reaction to the right, it is necessary to either use excess alcohol or remove one of the products from the reaction mixture. The second option is usually preferred for the reaction to proceed to completion. The reaction rate was found to be highest when 100% excess methanol was used. A molar ratio of 6:1 is normally used in industrial processes to obtain methyl ester yields higher than 98% (w/w).

Catalysts

Alkali metal alkoxides are found to be more effective transesterification catalysts compared to acidic catalysts. Sodium alkoxides are the most efficient catalysts, although KOH and NaOH can also be used. Transmethylation occurs in the presence of both alkaline and acidic catalysts. As they are less corrosive to industrial equipment, alkaline catalysts are preferred in industrial processes. A concentration in the range of 0.5–1% (w/w) has been found to yield 94–99% conversion to vegetable oil esters, and further increase in catalyst concentration does not affect the conversion but adds to extra cost, as the catalyst needs to be removed from the reaction mixture after completion of the reaction.

Mixing intensity

It has been observed that during the transesterification reaction, the reactants initially form a two-phase liquid system. The mixing effect has been found to play a significant role in the slow rate of the reaction. As phase separation ceases, mixing becomes insignificant. The effect of mixing on the kinetics of the transesterification process forms the basis for process scale-up and design.

Purity of reactants

Impurities in the oil affect the conversion level considerably. It is reported that about 65–84% conversion into esters using crude vegetable oils has been obtained as compared to 94–97% yields refined oil under the same reaction conditions. The free fatty acids in the crude oils have been found to interfere with the catalyst. This problem can be solved if the reaction is carried out under high temperature and pressure conditions.

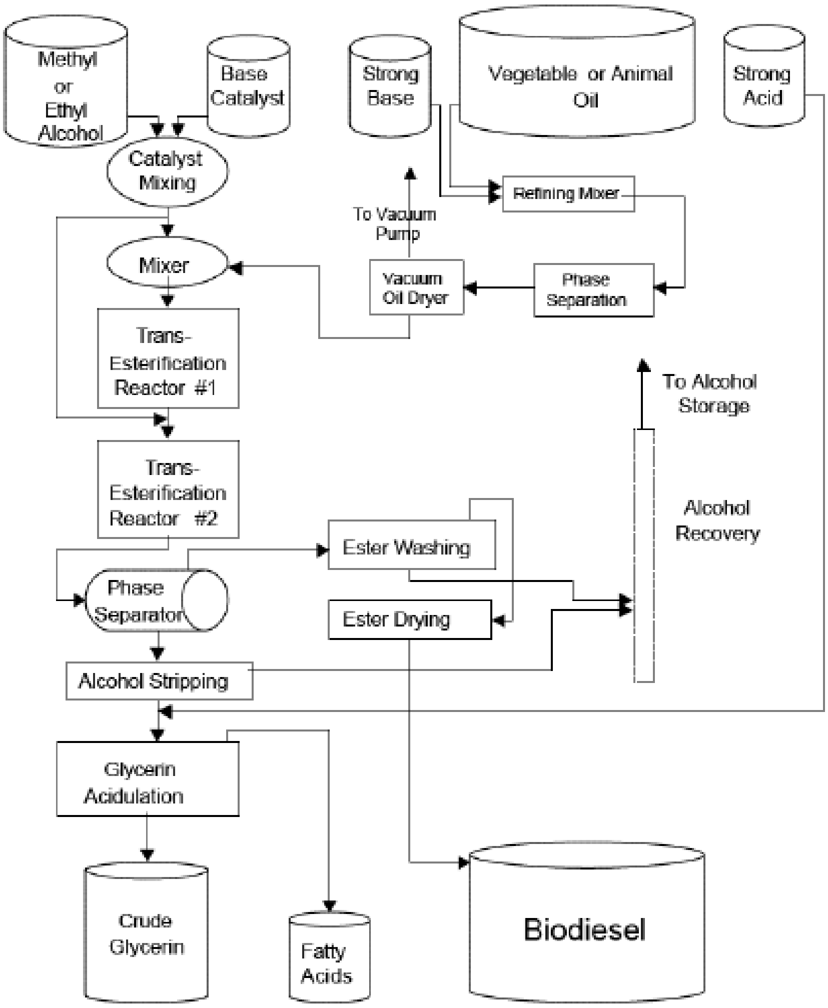


Figure 5: Flowsheet for biodiesel manufacture via transesterification
Source: Gonsalves [2006].

7.5.3 Glycerol separation

Glycerol is removed to a container through an outlet underneath the reactor while it is still warm to avoid solidification. The component of methyl ester which mixes with glycerol may be released from the reactor with the glycerol and left for 12 hours until the glycerol becomes solid. Then the separation of liquid methyl ester from glycerol can be done easily. The methyl ester separated from solid glycerol is refilled back into the reactor.

7.5.4 Glycerol purification

Half of the glycerol stream leaving the separator is excess methanol, most of the catalyst and soap. In this form, the glycerol has little value and disposal may be difficult. The methanol content requires the glycerol to be treated as hazardous waste. The first step in refining the glycerol is usually to add acid to split the soaps into FFA and salts. FFAs are not soluble in the glycerol and will rise to the top where they can be removed and recycled. Salts remain with the glycerol, although depending on the chemical compounds present, some may precipitate out. One frequently touted option is to use potassium hydroxide as the reaction catalyst and phosphoric acid for neutralization so that the salt formed is potassium phosphate, which can be used for fertilizer. After acidulation and separation of the FFA, the methanol in the glycerol is removed by a vacuum flash process, or another type of evaporator. At this point, the glycerol should have a purity of about 85% and is typically sold to a glycerol refiner. The glycerol refining process takes the purity up to 99.5–99.7% using vacuum distillation or ion exchange processes. Methanol that is removed from the methyl ester and glycerol streams will tend to collect any water that may have entered the process. This water should be removed in a distillation column before the methanol is returned to the process. This step is more difficult if an alcohol such as ethanol or isopropanol is used that forms an azeotrope with water. Then, a molecular sieve is used to remove the water.

7.5.5 Washing stage

Methyl ester after the reaction is still contaminated by other substances, i.e., soap (which results from the reaction between NAOH and free-fatty acid/oil), glycerol, NAOH and methanol (remaining from the reaction), and raw oil (which has not finished reacting). Methanol is removed from methyl ester while the mixture is still hot. The methanol vapour is pressurised to flow into a pipe system and eventually condensed into liquid by a condenser. The soap is cleaned out later by washing the mixture with warm water several times. The method is to spray water (about one-forth of methyl ester by volume) to catch the soap particles so they form a deposit underneath. After a short period, the water layer separates completely from methyl ester; then the water is released. The washing process is repeated for 4-5 times.

7.5.6 Finishing stage

The final stage is to wash out water remaining in the methyl ester by developing heat at 120°C for about 20 minutes and then leaving to cool down. The methyl ester is then contained in a container for further use.

7.5.7 Comparison of batch and continuous processing

Transesterification can be undertaken using simple equipment and biodiesel can be manufactured on a small scale using simple equipment such as buckets. However, to produce the fuel on a commercial basis, more sophisticated conditions are required to meet consistent quality requirements for the large volumes involved and to improve yields and rates of reaction. A number of process configurations are used with the principal alternatives being batch and continuous processes and high and low pressure systems. Generally, the more modern systems favour lower pressures because of the attendant lower plant costs and continuous processes are used in the larger and newer plant although some companies prefer batch systems. Plants have been built with capacities up to 100,000 tonnes per annum. As the transesterification process is common for both animal fats and vegetable oils, it is possible to interchange the feedstock in most types of plant, provided that account is made for the higher melting point of animal fats. However, a single stage process designed for vegetable oils may not be able to produce a biodiesel with sufficiently low Cold Filter Plugging Point - CFPP (a measure of low temperature waxing in diesel) as the mono- and di-glycerides produced from animal fats usually will have higher melting points than their vegetable oil counterparts. Two-stage transesterification, which appears to be the norm in most modern plants, will generally reduce the animal fat mono- and diglycerides to acceptable levels.

Batch processing is the classical method that uses a batch and stirred tank reactor as shown in Figure6. A batchwise system is able to operate in excess methanol and the presence of alkaline catalyst at atmospheric pressure and temperature of approximately 60–70^{o}C. The mixture at the end of the reaction is allowed to settle. The lower glycerine layer is drawn off while the upper methyl ester layer is washed to remove incorporated glycerol. The excess methanol is recovered in the condenser, sent to a rectifying column for purification and recycling. Typical reaction times range from 20 minutes to more than one hour [Van Gerpen et al. 2004].

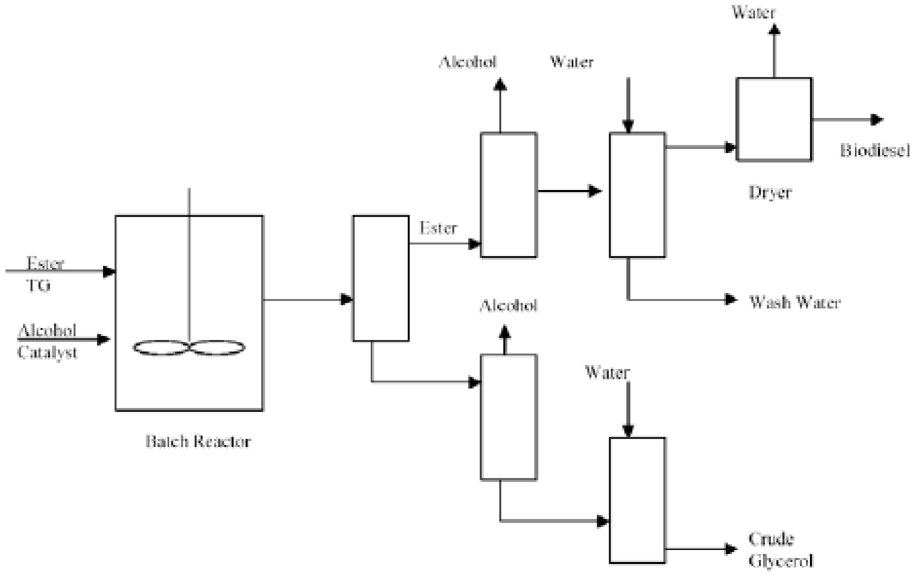


Figure 6: Batch processing of biodiesel
Source: Van Gerpen et al. (2004)

Continuous processing uses continuous stirred tank reactors (CSTRs) in series. The CSTRs can be varied in volume to allow for a longer residence time in CSTR1 to achieve a greater extent of reaction. After the initial product glycerol is removed, the reaction in

CSTR2 is rather rapid, with over 98% completion [Van Gerpen et al. 2004]. An example of a continuous reactor is shown in Figure 7.

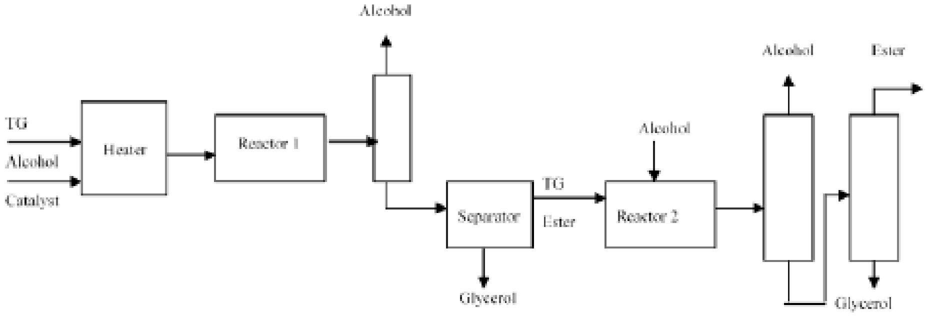


Figure 7: Continuous processing of biodiesel
Source: Van Gerpen et al. (2004)

The continuous system requires rather short residence times, as low as 6 to 10 minutes, for near completion of the reaction. This type of reactor is often operated at a high temperature and pressure [Van Gerpen et al. 2004].

Studies such as Gervasio [1996] as well as Ma and Hanna [1999] have shown that the continuous process is normally well suited for large capacity requirements and using unrefined feedstock. Furthermore, the unit can be designed to operate at various pressures or temperatures or at atmospheric pressure and slight temperatures. There are also some more benefits that can are gained from the continuous process such as lower production costs, shorter reaction time, greater production capacity, more recovery of high quality glycerol, less water present in the system, more concentrated glycerol, and lower energy requirement. However, the installation costs are higher than the batchwise system.

Economy of Scale

A significant factor in cost competitiveness is economy of scale. Large plants are advantaged by their ability to allocate flat fixed overhead costs over more litres of output as the size of the plant increases.

Low input, low output production is not profitable due to lack of supply of low cost feedstock and the variable quality and quantity of oil produced. These factors result in high unit costs per litre of output. Another observation was that small scale operations are generally dependant on cold press for oil extraction (unless they purchase the oil directly from a larger seed processing company). In systems that utilise cold press techniques, the meal left after press extraction can contain up to 10% oil. This carries two disadvantages the first is that meal sold for animal feed is generally priced according to protein content. The presence of oil lowers the protein percentage per unit weight. Secondly, the opportunity to process the oil remaining in the cake to biodiesel (and the resulting value) is lost.

Large scale operations carry the ability to produce by-products with a market value. Small scale plants often lack the ability to further refine co-products such as glycerine or produce it in any commercial quantities. As a consequence, smaller operations can have to pay for the removal and disposal of glycerine (which, when unrefined is classed as a hazardous product due to the methanol content). Conversely, larger scale operations have the ability to produce large quantities of high value glycerine with a number of end uses.
It is also these companies that have the ability to fund research into deriving high value products from the current low value commodity such as feed.

Source: Brown, 2007

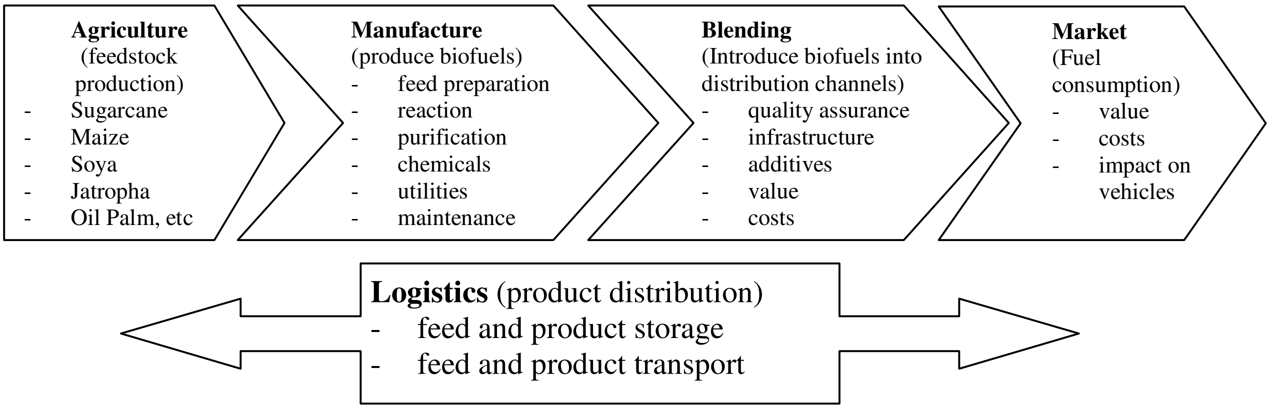
8 MARKET INPUTS, LINKAGES AND SUPPLY CHAINS

8.1 Biofuel Value Chain

The biofuels industry value chain starts with energy crop production and ends with the fuel at the end use. The product flow starts with the agriculture sector producing energy crops suitable for bioethanol and biodiesel production. Feedstock costs constitute 75-80% of the final fuel costs and it is important that the agronomic and harvesting practices are optimised to bring feedstock costs down. This is followed by processing industry phase were the feedstock is processed and converted using various technologies into desired biofuel. Although the manufacturing processes differ for the production of bioethanol and biodiesel, each process essentially converts the bio-material into the desired fuel products and co-products. Finally, the fuel enters the market where it is distributed either as a blend with fossil fuels or used neat, while co-products find application in various end-uses.

Throughout the chain, logistics play an important role in terms of storage and transport of feedstock as well as end-products. Transportation, especially road transport can contribute significantly to delivered fuel costs and the supply chain needs to be optimised to ensure that the energy balance and costs are minimised.

Figure 8: Diagrammatic Value Chain



8.2 Market Inputs

Biofuel markets are complicated, with many stages of production and key inputs coming into the sector from related industries. However, inputs into the biofuel production and supply generally follow closely those encountered for most agricultural commodities. Some of the most critical inputs along the biofuel value chain include land, capital, labour, energy, water, fertilizer and infrastructure. Land and water as natural resources presents huge challenges to biofuel production as their availability (in excess of traditional food crop production) determines successful feedstock production. Feedstock availability at a reasonable cost is a key determinant of the success of biofuel programmes. In general, 75% to 80% of the cost of final delivered biofuel is the cost of feedstock; other costs include chemicals, operational cost and labour.

8.2.1 Land

Current biofuel crops are not efficient energy producers and require vast surfaces of arable land that will not be available for other purposes, such as food production. Dedicated energy crops are likely to dominate future biofuel systems, posing a huge demand on land. Currently the best arable land for the agricultural use constitutes only 11% of the earth surface. While FAO is forecasting a 50% growth is required in food production by 2030 (which without productivity increases means extra land under cultivation), on the other hand arable land is reportedly shrinking due to desertification, land degradation and drought.

However, at current production rates of biofuels, the global arable land demand for biofuels remain small compared to total available land. This will obviously vary from country to country and decisions to grow energy crops for biofuels will have to take into account local context. Trostle [2008] examined land use in the top six biofuel producing countries and noted that despite rapid global expansion in biofuel production, total land cultivated in biofuel feedstocks amounted to about 19 million hectares in 2006/07, or only 3.4% of arable land in those countries (see Table 5). The US accounted for about 46% of the global total, followed by the EU and Brazil.

Table 5: Biofuel Production and Land Use by Major Producing Countries (2006/07)

Country	Biofuel		Feedstocks		Arable land	
	Ethanol	Biodiesel	Ethanol	Biodiesel	Area	Biofuel share
	Million litres				Million hectares	%
Argentina	-	532	-	Soy (100%)	28.33	2.5
Brazil	24,021	477	Sugarcane (100%)	Soy (66%)	59.09	5.8
Canada	723	123	Maize (70%) Wheat (30%)	-	45.73	0.6
China	2,132	136	Maize (70%) Wheat (30%)	-	143.26	0.7
EU-27	2,218	6,728	Wheat (48%) Sugarbeet (29%)	Rape (64%) Soy (16%)	113.72	4.4
US	29,481	2,314	Maize (98%) Sorghum (2%)	Soy (74%)	174.43	5.1
Totals	58,571	10,306			564.56	3.4

Source: Trostle [2008]

A number of studies (e.g. Matthews [2006]) show that land availability does not appear to be a major constraint to biofuel production in Africa. De Castro [2007] also adds that most African countries have enough land available for agricultural production. But what is not clear is what the actual status of the areas considered to have agricultural potential is: are these areas now forests, savannahs, deforested, marshes, etc? Such analysis would shed light into whether land availability is an issue or not. In their comparative assessment of all the world's major regions, Smeets *et al.* [2007] concluded that sub-Saharan Africa has the greatest bioenergy potential due to its large areas of suitable cropland and unused pasture land, as well as the low productivity of land under agriculture. Less than a fifth of sub-Sahara's non forested land suitable for agriculture was under crop production in 2005, and only about 2% of this land would be needed to meet biofuels feedstocks production for a 10% import substitution.

Where land availability is a serious issue it is necessary to carefully select feedstock taking into account productivity, yields and cost issues. For example, as shown in Table 6, oil yield per unit area of various biodiesel feedstocks provides investors and policy makers with insight into the potential productivity and hence feedstock availability given land requirement constraints.

Table 6: Characteristics of common biodiesel feedstocks

Crop	Oil in seed	Seed yield	Oil yield	Oil price
	(%)	(kg/ha)	(kg/ha)	(US$/kg)
Sunflower	48	2,200	1,056	0.99
Corn	3	8,000	274	0.71
Rapeseed (canola)	44	1,800	792	0.66
Coconut (Copra)	63	3,000	1,890	0.66
Soybean	18	3,500	630	0.55
Palm	18	25,000	4,500	0.42
Jatropha	35	6,000	2,100	0.30

]

8.2.2 Water

Agriculture is by far the biggest user of fresh water with world average of 70% of total human use, while industry and households consumes 20% and 10%, respectively [WWF, 2005]. Globally around 7130 km^3 of water is evapotranspirated by crops per year, excluding biofuel crops. Biofuel crops account for an additional 100 km^3 (1%). Total irrigation withdrawals amount to 2630 km^3 per year globally of which 44 km^3 (2%) is used for biofuel crops. It takes on average roughly 2500 litres of crop evapotranspiration and 820 litres of irrigation water withdrawn to produce one litre of biofuel. But regional variation is large [de Fraiture *et al.* 2007].

Biofuel scenarios project that energy crops will require an additional 30 million ha of cropped area (compared to 1400 million ha for food crops), 170 km^3 additional evapotranspiration (compared to 7600 km^3 for food) and 180 km^3 more withdrawals for irrigation (compared to 2980 km^3 for food). While for individual crops increases may be substantial, compared to the sum of all crops, increases are modest. These figures amount to increases in resource use of only 2-5%, levels too small to lead to major changes in agricultural systems at a global level [de Fraiture *et al.* 2007]. However local implications vary significantly across regions and countries.

8.3 Value chain linkages – Examples of Biodiesel value chain in India

As the biodiesel sector is still developing, no dominant way of organising the value chain has yet been established. Rather, different actors have established different systems and are in the process of trying out different ways of organising the value chain.

By studying 13 cases of value chain organisation in five Indian states, Altenburg *et al.* [2008] shows how specific forms of value chain organisation have evolved and the differences they exhibit with regards to investors, biodiesel application, plantation operations, processing, marketing as well as potential contribution to rural development.

As discussed below, three key main categories of value chain organisation were identified, taking the actor who organises the agricultural cultivation phase as a distinguishing feature. This is because this feature is linked to ownership of the land on which cultivation takes place, main risk-taker, and main motivations.

- Government-centred cultivation, characterised by cultivation on government (forest or revenue) and communal land, government as risk-taker, and social motivations (include employment generation for the rural poor, increasing the national forest cover, and protecting the soil from further degradation). Examples of this model are given in Table 7
- Farmer-centred cultivation, characterised by cultivation on private land, shared risk between government, farmer and private processing companies, and the objective of developing additional sources of income and/or new energy sources for sustaining their livelihood without incurring major investment risks. Examples of this model are given in Table 8.
- Corporate-centred cultivation, characterised by large-scale cultivation, private oil companies as the main risk-taker, and the objective of achieving high returns on investment. Examples of this model are given in Table 9.

8.3.1 Government-centred cultivation

Government-centred cultivation has been observed in the states of Chhattisgarh, Uttarakhand, and Andhra Pradesh. Cultivation of TBO feedstock (mainly Jatropha and Pongamia) is done on forest, revenue and communal land.

In Chhattisgarh, most of the plantations have been carried out by the Forest Department. The Chattisgarh Biofuels Development Authority (CBDA) distributes government funds at district level to the respective departments. The main funding source is the National Rural Employment Guarantee Scheme (NREGS). The state departments in charge cooperate with Panchayats to employ NREGS-listed labourers for setting up and maintaining the plantations. The case of Chhattisgarh is an excellent example for a well-functioning cooperation between state and private actors, because the latter are actively involved in setting up plantations and offer training facilities. Companies such as D1-BP Fuel Crops have buy-back agreements with Panchayats and Joint Forest Management Committees (JFMCs). Chhattisgarh also utilises SVO and biodiesel for rural energy generation. This approach of electrifying villages on the basis of locally cultivated Jatropha is carried out by two projects, the Chhattisgarh rural energy project by CREDA, and an electrification project of Winrock International.

In Uttarakhand, the main actors involved in the biodiesel production include the Uttarakhand Biodiesel Board (UBB), the Forest Department, the Forest Development Corporation and JFMCs. There is strong cooperation between UBB and the processing company, Biofuels Limited. In Uttarakhand UBB employs NGOs for the implementation of projects, whereas in Chhattisgarh all projects are carried out by government agencies. Jatropha is not a non-timber forest products (NTFP) in Uttarakhand, but through an agreement between the Forest Department and UBB, Jatropha can only be sold to the Forest Development Corporation.

The third case is cultivation of Pongamia on forest land in Andhra Pradesh. Work is organised through JFM-like committees. So far, 20,000 ha have been afforested with Pongamia, and 20,000 more are planned. Whereas in Uttarakhand members of JFMCs are paid individually, wages for its equivalent in Andhra Pradesh are channelled through joint account systems. After an activity has been carried out, the forest guard hands over a check to the JFMC. The Pongamia oil is expelled locally, which contributes to local value addition. So far, the Forest Department cooperates with one company, Southern Online, which buys the SVO and further processes it into biodiesel.

8.3.2 Farmer-centred cultivation

Farmer-centred cultivation is characterised by small to medium scale farmers who plant oil-bearing trees on their privately owned land. These farmers are linked to the market in four different ways:

- Production for own consumption on the farm;
- Arms-length relations with local processors;
- Buy-back arrangement with companies or governments;
- Integration in a cooperative.

The NGO “Humana People to People India” launched a farmer centred pilot project in Virat Nagar District in Rajasthan where it encouraged small and marginal farmers to plant Jatropha as boundary plantation around their fields. In doing so, the farmers cultivate 10-15% of their lands with Jatropha. The aim of the project – suitably called “Fences for Fuel” is to expel SVO and barter it back to the farmers for their Jatropha seeds. This way, the Jatropha growers will get access to SVO which can be used as fuel in their water pumps and vehicles.

Table 7: Different possibilities of organizing the biodiesel value chain (Government-centred cultivation)

Value chain Cultivation	**Provision of inputs for cultivation**	**Land used for cultivation**	**Responsibility for planting**	**Organisation of harvest and purchasing of the seeds**	**Organisation of processing**	**Consumption**
Case study Uttarakhand State	Uttarakhand Biodiesel Board, Forest Department, Biodiesel Ltd.	Forest land	Uttarakhand Biodiesel Board	JFMCs and similar groups harvest and sell seeds to Forest Development Corporation	Forest Development Corporation sells seeds to the biodiesel processing company Biodiesel Ltd.	Biodiesel for national market
Case study Chhattisgarh State	Forest Department, Agriculture Department, Horticulture Department, CREDA, Central government through MNRE (VESP)	Forest land, revenue land, communal land	Respective state department, Panchayati Raj	JFMCs and similar groups harvest and sell seeds either to Minor Forest Produce Cooperative … … or have buy-back agreement with private company (e.g. D1-BP Fuel Crops)	Minor Forest Produce Cooperative sells seeds on the market State government plans to set up processing units on district level in order to produce SVO for local consumption D1-BP Fuel Crops will set up processing units if viable	Biodiesel either for national and international market… … or for local electricity generation
Case study Andhra Pradesh State	Forest Department	Forest land	Forest Department	JFMCs harvest and sell seeds to Girijan Cooperative Corporation Buy-back agreement between JFMCs and private companies might be possible in the future	Girijan Cooperative Corporation sells seeds on the market	Biodiesel for national market
Case study Winrock International in Chhattisgarh State	Winrock International, Forest Department, Agriculture Department	Forest land, revenue land, communal land, private land	Winrock International takes supportive role on private as well as on public land	Villagers are responsible for harvesting, Winrock International assists in organising harvest	Village Electrification Committees organise processing	SVO for local electricity generation

In the State of Karnataka, farmers operate at arms-length with local processors. The oil expelling industry is well established in this state and the demand for oilseeds has risen considerably during the past few years. Most farmers in Karnataka do not cultivate Pongamia or Jatropha as a cash crop but as boundary plantation or on unfertile soils. Collection of the seeds takes place as an additional activity on the farms, and the produce is then sold via middlemen to the many existing oil expelling enterprises. Although middlemen sell the SVO on the market, most of it is used by the leather tanning and painting industries, and not for biodiesel production.

The most frequently encountered model is formed by farmers who have a reliable market link through a buy-back agreement or contract signed with a private company. This is common in Chhattisgarh (D1-BP Fuel Crops) and Tamil Nadu (D1 Mohan Bio Oils Ltd.), and in Andhra Pradesh with various enterprises that are working in the biodiesel sector.

D1 Oils plc. through joint ventures with BP and Mohan Breweries is one of the most important actors promoting contract farming in India. In Chhattisgarh, D1-BP Fuel Crops developed an approach that is based on so called Jatropha Interest Groups (JIGs). JIGs consist of 5-20 small farmers that grow Jatropha as boundary plantation or on small parts of their lands. Each JIG cultivates about up to 10 hectares and signs a buyback agreement with the company. D1-BP Fuel Crops guarantees to purchase the seeds, whereas the farmers commit themselves to selling to D1-BP Fuel Crops.

Apart from offering a buy-back contract to the farmers, D1 Mohan Bio Oils Ltd. Also provides assistance in training and linking up the farmers to credit facilities and crop insurances. Around 5000 such contracts are already in place and a transesterification unit of a capacity of 24t/day already exists in Coimbatore.

Unlike in Chhattisgarh and Tamil Nadu, Andhra Pradesh state is directly involved in contract farming through a public-private partnership model. Through an agreement between a biodiesel processing companies and the District Collector of Andhra Pradesh an area is assigned to companies for the development of the biodiesel sector. Those authorised companies in turn line up buy-back agreements with private farmers and set up the necessary processing facilities. Private farmers entering such an agreement are mostly small, since the government encourages the use of NREGS funds for the establishment of Pongamia cultivation on the land of farmers that own less than five ha. Guaranteed income from NREGS facilitates the farmer’s decision to try out a new crop. So far, five companies operate in seven districts, but more than 30 companies are in negotiations with the state government.

Management of the whole value chain can also be organised through cooperatives on local, regional and state level. Such a system is found in a pilot project in Hassan District in Karnataka, where the University of Agricultural Sciences, Bangalore, tries to establish cooperatives on local and district level in order to create a structure similar to the Indian dairy sector. With funding from the Government of Karnataka, a so called Biofuel Park near Hassan was established where TBO-related research takes place and seedlings of various oil-bearing trees are produced. Seeds are distributed free to farmers, and the

Biofuel Park provides technical assistance and consultancy to farmers. Clusters of village associations form cooperatives at taluk level owning an oil expelling and transesterification unit. Financing of the first set of processing units was financed by the

Biofuel Park, whereas a market-based expansion of the sector is expected in the long run. The SVO or biodiesel that is produced is marketed via a State Federation – a cooperative formed by the various cooperatives at taluk level. Use of the produced fuel within the region will be encouraged through the establishment of power generation plants in the village clusters. Funding for such plants is envisaged to come from the state.

Table 8: Different possibilities of organizing the biodiesel value chain (farmer-centred cultivation)

Value chain Cultivation	**Provision of inputs for cultivation**	**Land used for cultivation**	**Responsibility for planting**	**Organisation of harvest and purchasing of the seeds**	**Organisation of processing**	**Consumption**
Case study Free market in Karnataka State	Market actors provide input	Private farmland	Farmers	Middlemen purchase the seeds from the farmers and then sell them to private oil extraction units	SVO extraction is performed locally (private transesterification units might establish with a rising demand of biodiesel)	SVO/ biodiesel for the regional and national market
Case study Free market and public-private partnerships in Andhra Pradesh State	Free distribution of seedlings and other inputs to small and marginal farmers	Private farmland	Farmers Small and marginal farmers receive NREGS for planting	Farmers are responsible for harvesting on their lands Farmers either sell to Girijan Cooperative Corporation at minimum support price… *… or to a state-registered company (buy-back agreement)*	Girijan Cooperative Corporation sells seeds on the market Companies establish local processing facilities	Biodiesel for the regional and national market
Case study Free market and contract farming in Chhattisgarh State	500 free seedlings per farmer are provided by Agriculture Department Fertiliser and additional seedlings are subsidised by government	Private farmland	Farmers	Farmers are responsible for harvesting on their lands Farmers either sell to state purchase centres at minimum support price… … or to D1-BP Fuel Crops (buy-back agreement)	State purchase centres sell seeds on the market State government plans to set up processing units on district level D1-BP Fuel Crops will set up processing units if seed supply is sufficient	Biodiesel for the national and international market
Case study D1 Mohan Bio Oils Ltd. contract farming in Tamil Nadu State	Government provides 50% subsidy for seedlings	Private farmland	Farmers	D1 Mohan Bio Oils Ltd. purchases seeds from farmers under buy-back contract	Processing is performed by D1 Mohan Bio oils Ltd. D1 Mohan Bio oils Ltd. will set up further processing units if seed supply sufficient	Biodiesel for national and international market

8.3.3 Corporate-centred cultivation

Corporate-centred cultivation utilises large-scale block plantations with the aim of maximising productivity. Two cases in the states of Chhattisgarh and Tamil Nadu are examined.

Chhattisgarh state government plans to lease out large patches of revenue land to a Joint Venture with oil companies (with a 26% share of the government authority CREDA and a 74% share of an oil company). The Joint Venture company will manage Jatropha block plantations, while the oil company involved will process the seeds and use the end product for blending purposes. Through a notification, the Government of Chhattisgarh made leasing possible for Jatropha cultivation in September 2006. 157,000 ha of revenue land have been identified for Jatropha plantation by the various districts. In the long run, however, the companies will establish and maintain the plantations on the revenue land leased to the Joint Venture.

In 2005 when the programme was announced, the response from companies was large. However, it was suspected that many of the companies simply wanted to grab land as they were not in the fuel business. Thus, Chhattisgarh decided to only lease out land to Joint Ventures with public oil companies, such as the Indian Oil Corporation Ltd and Bharat Petroleum Corporation Ltd.

The Estate Model is being implemented in Tamil Nadu–where plantation is established on private land of absentee landlords. This strategy is employed by D1 Mohan Bio Oils to encourage absentee landlords to start Jatropha cultivation on at least 20 ha. Much agricultural land in the state is under the ownership of absentee landlords who invest in land holdings for speculative and fiscal reasons. D1 Mohan Bio Oils provides 70% of the input costs for a plantation as an interest free loan to the land owners and assists in organising planting, maintenance and harvesting. In addition, D1 Mohan Bio Oils provides a buy-back contract. Its objectives are to increase seed supply and to establish large Jatropha plantations that can be used for demonstration purposes to smaller private farmers.

Table 9: Different possibilities of organizing the biodiesel value chain (corporate-centred cultivation)

Value chain Cultivation	**Provision of inputs for cultivation**	**Land used for cultivation**	**Responsibility for planting**	**Organisation of harvest and purchasing of the seeds**	**Organisation of processing**	**Consumption**
Case study Cooperative farming in Karnataka State	State government provides free seedlings	Private farmland	Farmers	Village cooperatives (associations) purchase the seeds	District and taluk cooperatives will perform the processing and marketing State government will finance a first set of processing units	Biodiesel for the regional and national market
Case study "Fences for Fuel" in Rajasthan	Inputs are provided by Humana People-to-People India	Private farmland	Farmers	Farmers are responsible for harvesting on their lands	SVO extraction is performed locally	SVO (and maybe biodiesel) for local consumption
Corporate-centred cultivation						
Case study Leasing to Joint Venture companies in Chhattisgarh State	State government provided input on already established plantations Joint Venture companies will provide input on future plantations	Revenue land	Joint venture companies are responsible for cultivation on leased land	Joint venture companies organise harvest	Joint venture companies will perform all the processing	Biodiesel for the national market
Case study D1 Mohan Bio Oils Ltd. Estate model in Tamil Nadu State	Absentee landlords pay for input for the plantations D1 Mohan Bio Oils Ltd. gives 70% of the costs for the input as an interest free loan	Private land of absentee landlords	With the support of D1 Mohan Bio Oils Ltd., landlords hire specialized workers for the plantation work	Labourers are hired to harvest the seeds which are then sold under a buy-back contract to D1 Mohan Bio Oils Ltd.	Processing is performed by D1 Mohan Bio oils Ltd. D1 Mohan Bio oils Ltd. will set up further processing units	Biodiesel for national and international market
Built-Operate-Transfer Model of the Biodiesel Society of India (so far non-existent)	Private company that establishes energy village provides inputs	Communal land	Company employs villagers for planting and maintenance	Company employs villagers for harvesting Company and Panchayat share the benefit of the harvested seeds	Company will perform all the processing	Biodiesel for the market

The third possible type of corporate-centred cultivation is has been developed as a model by the Biodiesel Society of India. These are the so called Community Energy Resource Farms which are organised as a Build-Operate-Transfer (BOT) Model. In this model, Panchayats enter into cooperation with a private company. The community identifies unutilised part of communal land which can be made available for TBO block cultivation and hands it over to the company free of lease. The company, in turn, will establish a plantation – employing labourers from the respective village – and also manage the maintenance and harvesting for the next 25 to 30 years. Villagers will be involved in the activities; and eventually, the plantation will be transferred back to the Panchayat. Until this re-transfer has taken place, community and corporate share the yield from the plantation. In the first 20 years 70% to 80% of the yield will remain with the company, from the 20th year onwards, the share will be equal (50%-50%). The objective is that a sustainable plantation is built up and that, on regaining control of the plantation, the community still sell the yield to the formerly involved company.

8.4 Supply Chains

Generally, the biofuel supply chain consists of actors and activities in feedstock production, harvesting, pre-treatment, conversion, transporting and distribution. Below is presented some selected supply chains in Asia and South America.

8.4.1 Jatropha supply chain in Thailand

According to Practical Action Consulting [2009] the University of Kasetsart in Thailand has been working with at least 500 farmer members of the Viengsa Agricultural Cooperative to develop Jatropha primarily for biodiesel since 2006. The Jatropha supply chain has been developed by the University of Kasetsart and its key partner - the Viengsa Agricultural Co-operative. The Co-operative members are the principle market chain actors in this project and their working relationships are key to its success. Once harvested by the farmers, the seeds, hulls, leaves and stems are sold on to other members of the Co-operative for processing. Biodiesel is sold to members of the Co-operative at about 20% cheaper than open market price, with priority going to those members who need fuel for tractor engines. Organic fertilizer is available to the Co-operative for use by members on crops such as rice, vegetable and fruit. Charcoal is sold direct to households for use in cooking. A community micro power plant is also due to be set up to serve five to ten nearby communities within a 50km radius (all Co-operative members). Biomass or charcoal will be sourced from Co-operative producers to power the plant’s steam turbine. See Figure 9.

For support, the University runs the Jatropha School which provides training on Jatropha production and processing into marketable products. By September 2008, more than 5,000 participants had graduated from the school. The project has also trained participants to design and construct machinery to process the various parts of Jatropha into products to suit different scales of production. The Co-op provides supporting services to its members in term of a soft loan, technical support in seed production from extension officers and technology support to the biodiesel processors. The Department of

Co-operative Promotion is part of the Ministry of Agriculture and Cooperatives and is the lead Government agency to promote and develop co-operatives and farmer groups.

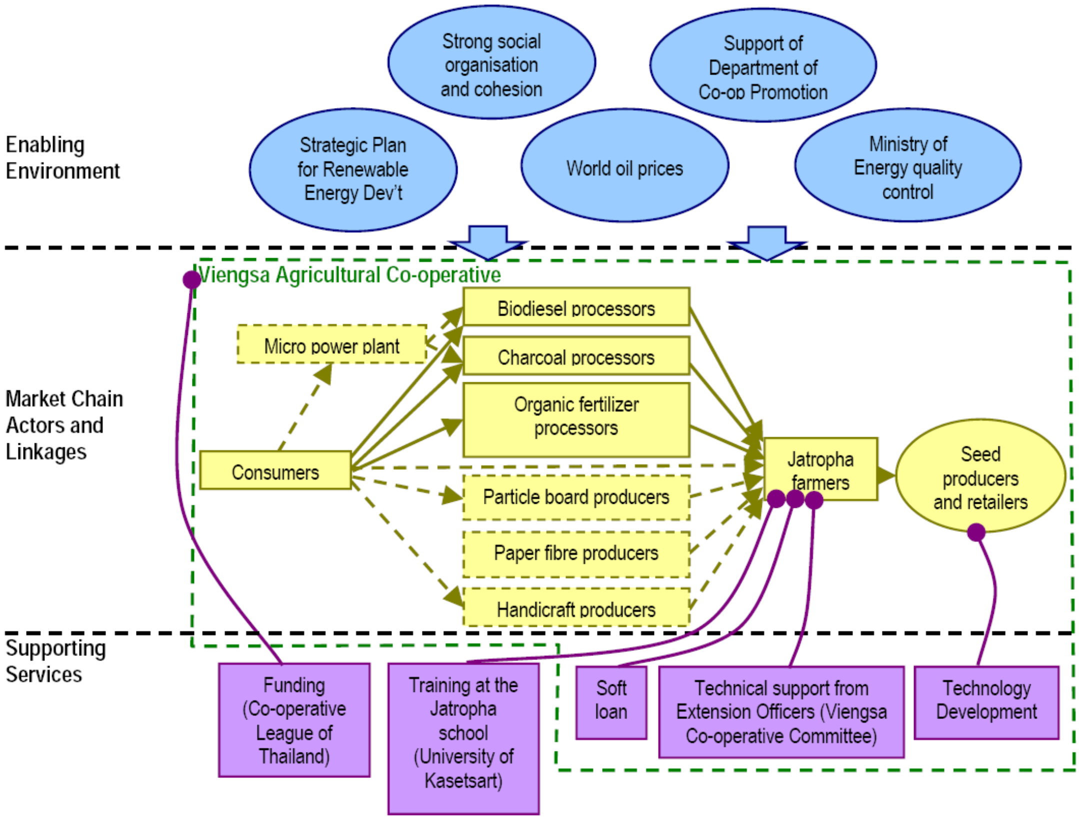


Figure 9: Community based Jatropha biodiesel Supply chain in Thailand
Source: Practical Action Consulting [2009].

8.4.2 *Biofuels for Rural Development, Guatemala*

The Biodiesel for Rural Development project has as an objective the improvement of livelihoods for the poor in Guatemala adding an additional crop that produces income, and diversifying crops for soil recuperation. It was developed and is being implemented by TechnoServe, a global NGO. The project promotes the formation of co-operatives of small producers to plant Jatropha and mainly sell the oil to larger processors and eventually to large companies.

To begin, the project involved an industrial partner who purchased the transesterification equipment. For future clusters, the co-operative itself will purchase the extraction equipment and sell the oil. TechnoServe supports preparation of business plans, designed to support small farmers in the vicinity.

Within the main market chain, the base organization proposed will be a co-operative or similar institution which will group small farmers into clusters. Once organised and trained, they can be empowered to access financing to purchase the extraction equipment to sell the oil. The next link is the involvement of an industrial partner who will purchase the transesterification equipment and buy the seeds from small farmers and process the product, because this step needs a high level of quality-control. For the first cluster, the main chain starts with the extraction of oil from Jatropha seeds by the donated equipment; then the small producers have the option to sell the oil or pay the industrial partner for the process and keep the biodiesel for personal use, or sale. The industrial partner will commercialise the product starting in the local agricultural market and after a certain volume is produced, considering exports to nearby countries or selling to a larger company. In new clusters, the total equipment could be acquired by the industrial partner, who will provide support and service to small farmers in the cluster. The by-products include the seed shells, the seed-cake, and the leftovers of the fruit, which will be used to make fertiliser. The by-product of the transesterification process (glycerin) will be sold to local cosmetics companies.

Regarding supporting services, TechnoServe and other support institutions are focussed on training, teaching, guiding and supporting the effort of the initiative to reach the poor and improve livelihoods. Additionally the creation of strategic alliances with Universities and research centres with incorporation of larger local producers, as well as private investment, has been crucial. TechnoServe is providing the transportation in the initial stages of the project’s operation, although with small farmers’ families close to the plant, transport distances are short and as the project becomes established this service will end.

The project plans to form groups of small farmers organised into co-operatives (or similar organisations) to manage the Jatropha plantations and fences, complemented with an industrial partner who will process the product. Once the crop is ready, recollection of seeds from production locations will be coordinated by a transportation arrangement, for which a small fee is being considered. Once the seeds arrive to the processing unit, oil is extracted, and processed into biodiesel. The seed cake is used to produce fertiliser, to be sold later to interested users.

The importance of the industrial partner is the quality control of production. Later on, when a critical mass of biodiesel is produced, quality will be an important factor for exports, commercialisation at wider levels etc.

The organisations that will be formed pulling together small farmers will grow the plants, collect the fruit, and extract the seeds. They will use shells, fruit and seedcake to produce fertiliser. The seeds will be transported to the processing plant and payment will be made according to the contract with the industrial partner. The relationship is interdependent and currently has no competition or competing interests.

A three pillar strategy was planned with a value chain and selected partners. The first pillar is the small producers organised in co-operatives or similar organisations, and TechnoServe partnered with USAID and AEA (Energy and Environment Agency). The second pillar is research and development and here the partners are Guatemalan universities and private research companies. The third pillar is formed by large scale investors, which will come into play once several clusters are in operation, buying the oil directly from the co-operatives, or through the industrial partners.

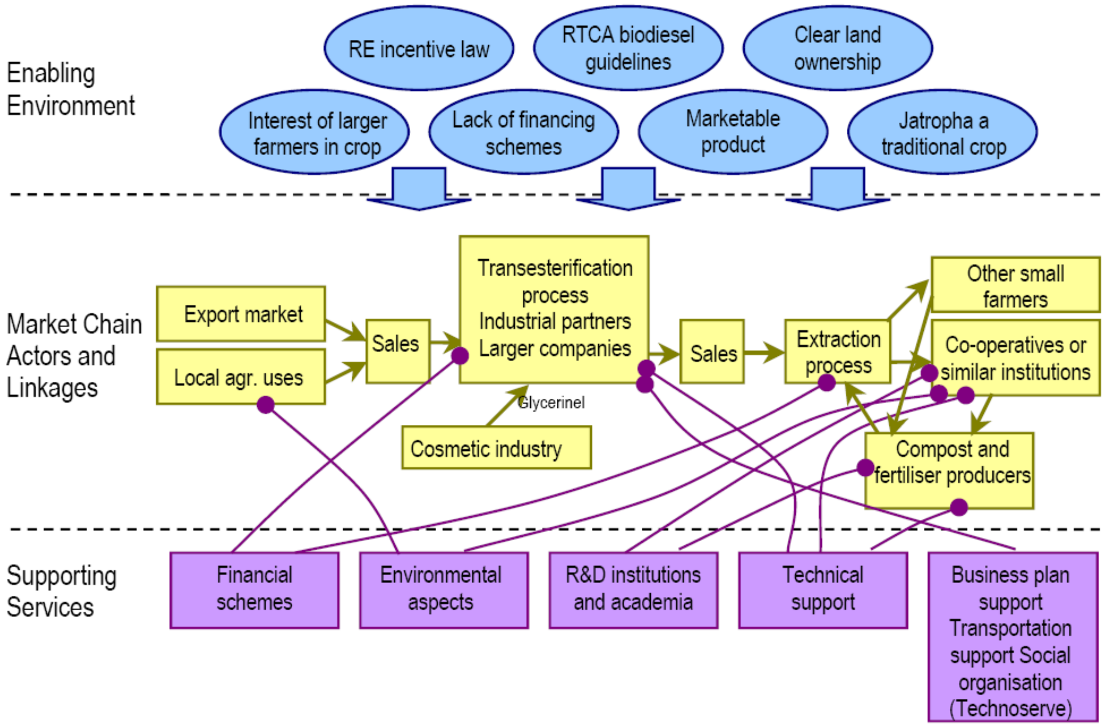


Figure 10: Biodiesel for rural development supply chain - Guatemala
Source: Practical Action Consulting [2009].

9 FINAL MARKETS, DISTRIBUTION, TRANSPORTATION

There exists today a significant demand in industrialized countries for biofuels, driven largely by regulatory mandates for blending of biofuels into petroleum fuels. Between 2000 and 2007, biofuel production rose by nearly 250% to about 70 billion litres [Larson, 2008]. This demand is likely to grow considerably in the years ahead, driven by increasingly ambitious regulatory mandates, sustained high oil prices, and energy security concerns. Biofuel demands in many developing countries will also grow, driven by similar factors. For instance in Asia, China and India, by their sheer size of population, rapid economic development and increasing demand for vehicles, pose to be the largest markets for biofuels. From 1991 to 2007, China increased its automobile population from a little more than five million to more than 40 million, with an average annual growth rate of nearly 15% [Gonzales, 2008]. With this trend, China will require more gasoline, which will make the prospect for biofuel substitution very high. Opportunities for trade in biofuels or biofuel feedstocks will be expanding. Projections for the global market for ethanol are estimated at about 125 billion litres/year and 24 billion litres of biodiesel by 2017 [OECD/FAO, 2008].

Consumption

Both SVO and biodiesel are suitable for final consumption. SVO can be used for lighting (replacing petroleum in lamps) and cooking (in specially designed cooking stoves). It can also replace conventional diesel in engines (e.g. electricity generators or water pumps). Since SVO has a very high viscosity, fuel injection pumps need to be modified or the abrasion of the engines will proceed much faster. Hence, operation and maintaining costs of engines running on SVO are higher compared to those running on conventional diesel. Fuel properties of biodiesel, on the other hand, are a lot better than those of SVO. Thus, replacing diesel with biodiesel instead of SVO reduces operation and maintaining costs. Some projects aiming at rural energy security use SVO for their machines and electricity generators while others first transesterificate and use BD for the same purposes. The advantages of the latter are better fuel properties, leading to more efficient fuel burning and less pollution. There are, however, economic and safety issues with the process of transesterification. Additional technology and equipment as well as other inputs (methanol, catalyst) are needed to process SVO into BD.

This means additional costs both for investment and maintenance. Also, qualified personnel have to be trained to operate the complicated transesterification process. Besides, this process is a dangerous one since highly inflammable material such as methanol is used. These issues, however, could be resolved with careful planning and implementation. A solution to this problem of viscosity is to blend diesel with either SVO or biodiesel. A SVO-diesel blend, though, still requires a modification of the engine for proper functioning in most cases. The characteristics of the SVO can vary a lot due to differences in seed quality and extraction methods. Therefore, the percentage up to which a blending of diesel with SVO is possible highly depends on SVO quality and the kind of engine. By contrast, the characteristics of biodiesel are rather consistent because of the standardised chemical reaction processes during transesterification. Blending diesel with biodiesel is therefore much more efficient. Depending on the study, such a blending up to 50% is possible without major operational difficulties for engines (Jongschaap *et al.*2007:15).

By-products and alternate uses of SVO and biodiesel

Several by-products have economic value. Oil-bearing trees not only produce seeds/fruits, but their leaves, latex and wood can also be used. Leaves of some oil-bearing trees can serve as valuable organic fertiliser, and both leaves and latex of some species are used for medicinal purposes. When trees or bushes are pruned, branches can be used as firewood or – like any other biomass – for biogas production. Furthermore, fruit hulls are proper for all the possible uses mentioned above – as organic fertiliser, for burning, for medicinal purposes as well as for biogas production.

Two other important by-products of SVO/biodiesel production emerge during further processing: seed cake and glycerol. After extracting the oil, the particulate material of the kernel, which is called seed cake, remains. It can be used as an organic fertiliser. Since yields increase a lot when fertiliser is applied, the seed cake can be taken back to the field and facilitate cultivation. In addition, producing biogas from the seed cake is also possible.

Theoretically, seed cake could also serve as fodder for animals. However, Jatropha seedcake has to be detoxified, but detoxification has only been successful at laboratory scale (Jongschaap *et al.*, 2007). The process – if possibly applied in the field – would currently be very expensive, so that Jatropha seed cake as fodder could not take a stand on the market.

Glycerol (Glycerine) is removed from the SVO during transesterification. It is an important ingredient to many kinds of cosmetics, soaps and pharmaceutical products. If the demand of glycerol on the market is high and the by-product can be sold at a good price, biodiesel production can become a lot more cost-efficient. However, this is not an important issue in India (yet). During the course of the field research for this study, glycerol has not played a role in any of the cases examined.

Compared to the various by-products, the opportunities for alternate uses of SVO or biodiesel are very limited. The single most important mode of consumption is the use as some kind of a fuel. Biodiesel, in fact, can only serve as petrol. Some SVO – depending on their plant of origin – can, on the other hand, be consumed as food, but since Jatropha-based SVO is toxic, it cannot enter the edible oil market. An alternate use of Jatropha-based SVO lies, however, in the production of soap. A soap of good quality can be produced from SVO and in some countries (e.g. in Mali and Haiti), there are projects promoting this kind of processing in order to generate income for poor rural families. In India, however, the production of Jatropha based soap is currently not competitive on the local soap market [Altenburg, *et al*, 2008].

In each process step of biofuel production different actors are involved. Biomass is produced and transported by farmers. It is sometimes also transported by logistic services or by the biomass conversion industry itself. The conversion of biomass to biofuels can be either made by farmers or by industry, which is more common. Finally, biofuels are distributed by logistic services or fuel stations and consumed by private or industrial consumers.

The bioenergy production chain for soybean is shown in figure 11 After harvesting, the product is transported to Junín for oil extraction. This is the closest processing unit for soybean production in the region (Manzanara *et al.,* 2008). In Argentina, only larger agricultural companies directly export the soybean to the oil extraction companies. The smaller to medium sized producers sell their soybean in practice via cooperatives or stocking companies spread in the country, who take care of the merchandise and send it to industry or to the harbour, where it is commercialized via the stock market. After oil extraction, the crude soybean oil is transported to Rosario to be converted to biodiesel. This end product is exported to Rotterdam or used in the local market.

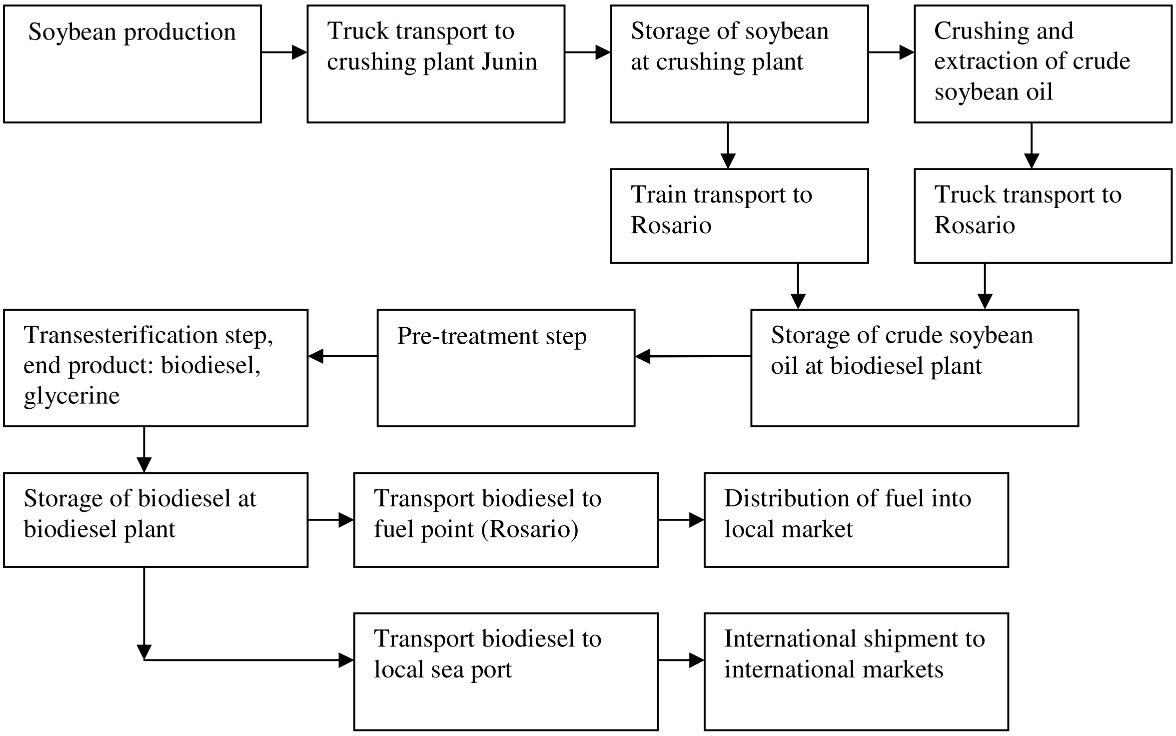


Figure 11: Soya bean to biodiesel supply chain

Potential Glycerine Markets

Although few countries have started to conduct research for the further treatment of glycerine, it is a by-product that can be used in a wide range of existing markets, having many end uses. Some of the uses are in the pharmaceutical and cosmetics industry, tobacco industry, food industry and other miscellaneous uses throughout industry. Glycerine is derived from a number of industrial processes. Fatty acid production and soap production are together responsible for 65% of global glycerine production, with fatty esters and alcohols production, synthetic petrochemical manufacture and biodiesel production accounting for the remaining 35%. Crude glycerine is 70% pure and is usually refined to further points of purity up to 99%.

Source: Ballard-Tremeer & Skordili, 2007

One of the biggest problems with biodiesel is its lack of uniformity. One variation that affects the biodiesel product is the different composition of mono, poly and saturated fats in the feedstock oil. Current breeding programmes for mono-unsaturated oil at 94% and less than 2% saturated fat are seen as the ultimate starting feedstock oil for biodiesel. Genetic modification programmes are focusing on the fatty acid profile as this is easier to manipulate than oil yield. Saturated fat content is directly proportional to the cetane number and oxidative stability of the final fuel and inversely proportional to the gel point (cold weather performance) of the final biodiesel. For example, soy oil at 15% saturated fat has a gel point of approximately –0.5 ºC, canola at 6% saturated fats has a gel point of - 10º C and rapeseed at 4% saturated fat has a gel point of -15ºC (this is similar to mustards). Correspondingly, oxidative stability increases in order of rapeseed, canola then soy.

Source: Brown, 2007

9.1.1 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. According to Biswas, *et al.* [2006], biodiesel can be stored up to a maximum of 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 and 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.

10 SOCIO-ECONOMIC IMPACTS AND RURAL LIVELIHOODS

10.1.1 Energy Security and Foreign Exchange Savings

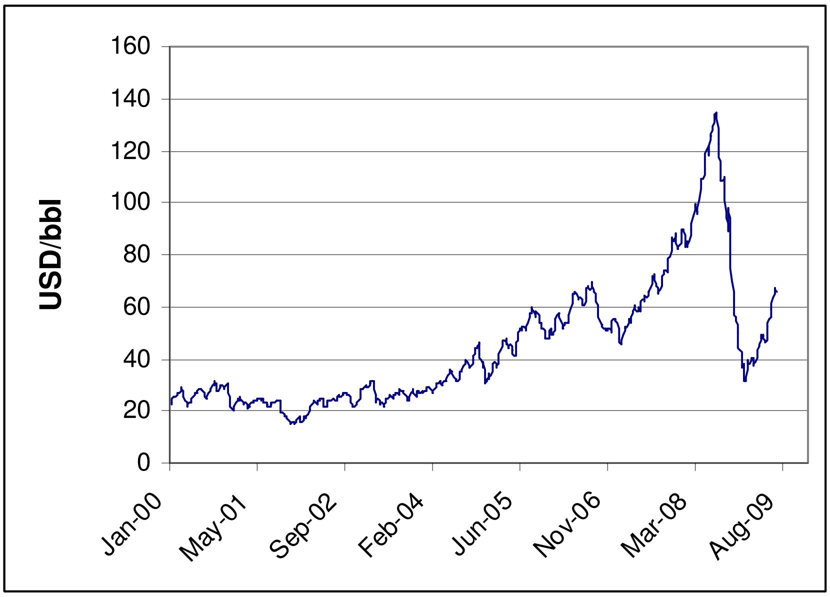
Energy security has become a key concern in the region over the last few years for various strategic reasons. Fears of oil supply disruptions, high oil prices, power blackouts, fuelwood shortages have all become issues of concern especially for poor oil importing African countries. For landlocked countries, landed fuel costs are high and supply lines are vulnerable to supply disruptions in the case of civil unrest or natural disasters. For most African countries, the ability to meet growing demand for energy from imported or internal sources; diversification of energy supply sources; securing capital and financing for investment in resource development and infrastructure, technological solutions to reduce dependence on imported supplies and meeting people's basic energy needs and creating effective demand for energy services are some of the key energy security challenges.

Given the widening gap between energy demand and supply in the region, it is imperative that measures be instituted to improve access to especially modern energy forms and facilitate sustainable development. Biofuels are seen as an opportunity to locally produce modern energy carriers such as liquid fuels for transportation and electricity, reducing the need for imports and thus improving security.

The impact of oil prices

Crude oil prices have been volatile since 2004, rising from less than USD40 a barrel (bbl) in 2004 to a record high of USD147 in July 2008, boosted by a jump in oil demand from emerging economies (especially China, the world's second-biggest energy consumer), limited capacity along global supply chains exacerbated by worries about supply from key producers such as Russia and Nigeria as well as political instability in the Middle East (see **Figure 12**). Most African countries are classified as low-income economies and rely heavily on imported oil and hence have been adversely affected in terms of balance of payments and economic growth rates. This has lead to increasing debt problems warranting major strategic shift in energy planning [Matthews, 2007]. Prices have come down strongly in 2008 however, dipping below USD35 in December 2008 before steadily rising again in February 2009 to current levels of over USD70. This volatility remains cause for concern for heavily indebted oil importing countries, especially in Sub-Saharan Africa.

Figure 12: Trends in oil prices (Weekly US Spot Price FOB Weighted by Estimated Import Volume)



Source: EIA (1 July 2009)

Africa's proven oil reserves account for about 10% of the global reserves of which over 80% are in only four countries (Algeria, Libya, Nigeria and Angola). In 2005, 16 African countries were crude oil producers of which 13 were net oil exporters. Most African countries (39 countries) are net oil importers including some oil producing countries. The high cost of oil imports is compounded by the fact that a large number of African countries are landlocked, which increases landed oil prices due to high land transportation costs as well as vulnerability to disruptions.

Economic impacts of high oil prices

Energy imports in Africa account for up to 28% of total export receipts and dominate import expenditure. Oil imports make up between 10-25% of total imports of at least 28 African countries. This has serious implications for development in the region. An increasing body of literature is linking lack of access to modern energy services to underdevelopment in SSA. The World Bank estimates that high oil prices, together with domestic capacity constraints and limited export demand, reduced growth among oil-importing developing countries by up to 7% between 2002 and 2006. A recent World Bank study also highlights that in general, lower income countries dependent on oil imports are the worst affected by oil shocks[9].

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[9] Escalating oil prices since 2002 has caused poverty to rise by as much as 4-6% in some countries, with nearly 20 countries experiencing increases of over 2%. Even the relatively modest 2003-2004 hike in oil prices implied increases in national oil bills of between 1.5 and 5% of GDP for oil importing countries with high energy intensive economies [IEA, 2006].

When prices rise, the very security of the poor is threatened as their ability to purchase sufficient fuels for their cooking, heating and lighting needs is greatly diminished. The International Energy Agency projects that a sustained increase of USD10 per barrel in oil prices would result in a loss of more than 3% of GDP in the year following the increase in SSA [IEA, 2004b].

Apart from dampening economic development, energy shortages also discourage investment. According to the World Bank, firms in developing countries lose about 5% of their annual sales due to power outages. Its Investment Climate Surveys have consistently found that unreliable or unavailable modern energy services is a “major or severe obstacle to doing business” for 44% of firms in SSA.

10.1.2 Rural Development and Agricultural Diversification

Access to modern energy services is severely limited for the predominantly rural African population. Sub-Saharan Africa has the lowest per capita electricity consumption in the world with an average of 178 kWh, excluding South Africa, equivalent to 2.4% that of developed regions. Only 25% of SSA’s population has access to electricity and this figure dips to 8% for rural areas. Electrification is as low as 5% in some countries while per capita electricity consumption is below 50kWh in parts of the region [IEA, 2006].

The predominantly poor rural population in the region is therefore heavily dependent on traditional biomass energy, mostly in the form of fuel wood. For most of SSA, traditional biomass energy accounts for between 50 to 90% of national energy supply. Most of this energy is inefficiently consumed by the domestic sector, illustrating the underdeveloped nature of commerce and industry as well as the poor standards of living. Although the region is generally sparsely populated at national levels, there are usually pockets of high population densities in many countries where competition for biomass resources is rather high. In such areas, environmental degradation is profound and fuel wood shortages are common, resulting in the use of lower order fuels and other attendant socio-economic burdens. This acutely constraints development of rural economies and undermines any efforts to enhance income-generating activities and alleviate poverty.

Proponents of biofuels observe that agricultural development linked to fuel supply has the potential for improving rural livelihoods. Farmers expanding into agricultural production for fuel could create new income sources for themselves and linkages to new areas of economic growth for communities and businesses, and could hence use the additional income to compensate for lower food production (i.e. purchase food rather than grow). However, depending on the development trajectory, this could result in negative impacts such as increased food prices. Vulnerable groups could suffer food insecurity as a result, and the societal costs of the expansion could outweigh the energy and economic benefits. The food vs fuel issue is discussed in more detail in section 10.1.3.

Agricultural diversification

Biofuels could offer an opportunity for diversifying agricultural products in African countries. There are hopes that the high producer prices would actually be welcome by African farmers who have struggled against organized dumping of agricultural produce from subsidized farming in developed countries. For example, the sugar industry has faced increasing competitive pressures in recent years, due to factors such as saturated demand in industrialised countries, competition from other sweeteners, and low and/or fluctuating sugar prices. Countries in the African, Caribbean and Pacific region (ACP) have had to deal with changes in EU and USA sugar policy especially the withdrawal in preferential raw sugar markets in the EU and USA. These difficulties have increased economic incentives for sugar producers to diversify their product portfolio by investing in biofuels [Yamba *et al.* 2008].

In the USA, maize farmers have been complaining that maize prices have remained virtually unchanged since World War II. But now the situation has changed and increased demand from ethanol production has raised average maize prices by 70% and is driving an economic resurgence in rural areas such as Nebraska. The huge maize surplus in Nebraska have in the past been responsible for depressed maize prices and severely limited the value of the state's largest crop produce. The livestock industry historically purchased a third of annual production, but the rest was exported, supposedly at uncompetitive prices.

Furthermore, the failure of the WTO Doha Round in opening agricultural markets of many OECD countries (as well as to restrict subsidized agricultural exports) is expected to shift the focus of traditional farming for cash crops to dedicated bioenergy crops which have the prospect of higher revenues on international markets if converted into biofuels.

Job creation

One of the expected outcomes on the economy of biofuels is the creation of rural jobs in the agricultural sector, in the commercialisation of new market commodities (oil, ethanol, gelfuel) and in new products (energy, fertilizers, animal feed, etc.). It is expected that the employment would drive up rural incomes and increase access to basic services. In addition, biofuels production would promote rural industry and help curb urbanization.

Proponents of biofuels claim that the current ratio of jobs created per unit of energy produced in the biofuels sub-sector is much higher than for other energy sources; if one takes the oil industry as the baseline (oil = 1) then hydroelectric power creates 3, coal creates 4 and ethanol creates 152 jobs. Also, job generation in most other industries requires higher investments [Moreira, 2004]. This analysis is however based on the Brazilian experience and is not necessarily replicable. It also assumes that biofuel production is not technology intensive and employs manual labour, especially in feedstock production.

Another study done in South Africa [Agama, 2003] quantified and characterised the direct and indirect jobs that could be created in South Africa through implementation of wind, solar and bioenergy for both electricity generation and thermal/transport energy services. The study also compares the renewable energy technologies (RETs) findings with employment associated with conventional energy sources such as coal, nuclear and natural gas. Within the RETs direct job creation in the biofuels sector is enormous relative to other surveyed technologies.

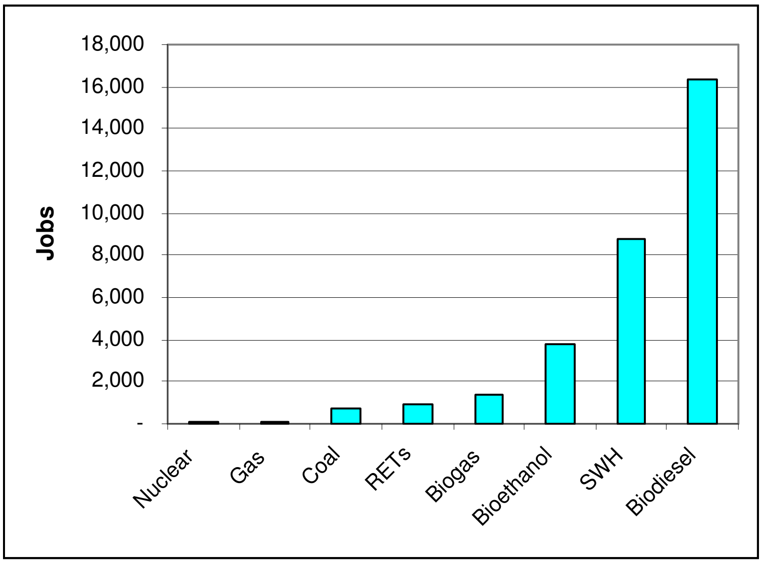

Figure 13: Comparison of gross direct jobs/TWh-equivalent by technology
Source: Agama [2003]

SOCIAL RISKS

10.1.3 Impacts of biofuels on food security

Perhaps the most controversial and worrisome issue surrounding biofuels is the food versus fuel debate. Food security is a central component of sustainable livelihood. One of the questions posed by an expanding biofuel sector is whether biofuels production will compromise agricultural production and food security triggered by competition for land and water between fuel and food crops. Biofuel interest seems to have coincided with dwindling global food stocks at a time when reducing hunger remains a serious global challenge. The number of people suffering from hunger globally has increased to 854 million people and has been rising since 1996 [GBEP, 2007]. Already protests against rising food costs are increasing around the world e.g. Mexico, Haiti, Pakistan and Indonesia. The World Bank estimated that 33 countries could face social unrest because of high food and energy prices [Reuters, 2008b]. According to [UN, 2007], there is a serious risk of diverting food to fuel production that would leave the poor and hungry more vulnerable to rapidly rising prices of food.

Brown [2006] argues that because the biofuels industry can pay more for agricultural feedstock than the food industry, cars, not people, will ultimately claim most of the additional grain, sugar cane, rapeseed and palm oil. Whenever the food value of one of these commodities drops to or below its fuel value, the market will convert it into fuel. Hence there are fears that this will create competition between the fuel needs of the world's 800 million affluent automobile owners and basic food requirements of the two billion poorest people in the world. Brown urges the global community to rethink biofuels and gives some rather discomforting figures. For example, the grain required to fill a 100-litre sports utility vehicle (SUV) gas tank with ethanol will feed one person for a year.

For a continent with some of the largest share of poor people, many of whom spend half or more of their income on food, rising grain prices can quickly become life threatening in Africa. The broader risk is that rising food prices could spread hunger and generate political instability in low-income countries that import grain. This instability could in turn disrupt global economic progress.

Causes of high food prices

A USDA report, Trostle [2008], provides an in-depth assessment of the factors contributing to the recent increase in food commodity prices. Another study, Banse *et al.* [2008], also provides similar analysis for the underlying causes of food price increases. In the two reports, it is argued that all commodity prices have risen in recent years and not only food has been affected. Figure 14 depicts the price index for food commodities along with an index for the average of all commodities and an index for crude oil. Although the food commodity index has risen more than 60% between 2006 and 2008, the index for all commodities has also risen 60% and the index for crude oil has risen even more. From 1999 to March 2008, food commodity prices rose by 98%; the index for all commodities has risen 286%; and the index for crude oil has risen 547%. In this perspective, the recent rise in food commodity prices is moderate.

Trostle [2008] and Banse *et al.* [2008] identified several factors that contributed to these price increases. They blame long-term trends that led to slower growth in production as well as rapid growth in demand that together contributed to a sharp downward trend in world aggregate stocks of grains and oilseeds that began in 1999. In addition, recent factors that have further tightened world markets include increased global demand for biofuels feedstocks and adverse weather conditions in 2006 and 2007 in some major grain and oilseed-producing areas such as Australia, Ukraine and Europe. FAO statistics show that these three regions contributed on average 51% of total world barley production and 27% of total world wheat production for the period 2005-2006.

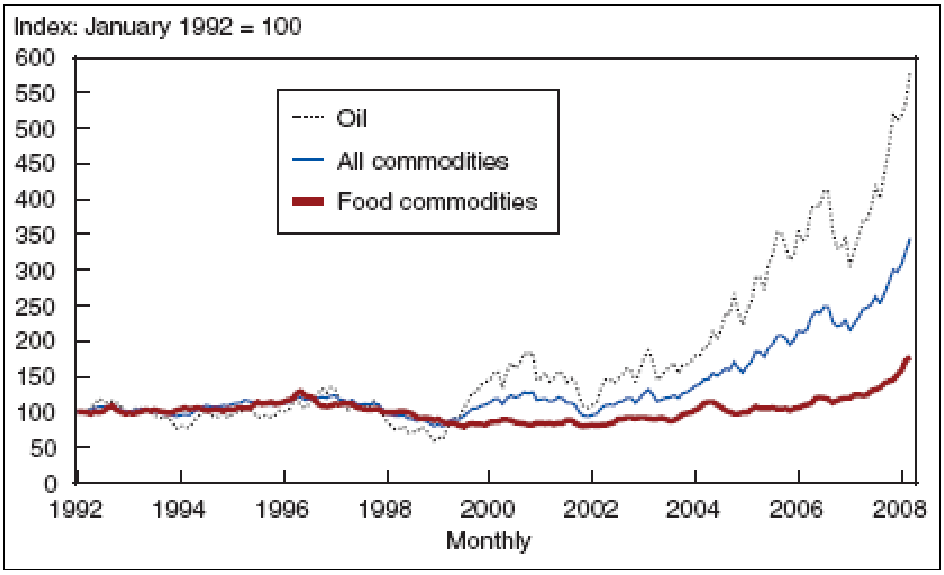

Figure 14: Index of Oil, Food and Industrial Commodities (1992-2008),
Source: Trostle [2008]

Recent developments that have put upward pressure on food commodity prices by further restricting available supplies or increasing demand for food commodities include:

- record low global inventory levels
- weather induced supply side shocks
- the devaluation of the U.S. dollar (world prices are denominated in dollars and the dollar depreciated against most currencies since 2002)
- rising energy prices with record oil prices (higher energy prices lead to higher food prices as costs (e.g. fertilizer, processing, and transport increase)
- increases in agricultural costs of production
- surging outside investor influence
- growth in foreign exchange holdings by major food-importing countries
- structural changes in demand for grains and oilseeds due to biofuels
- change in diet in emerging economies
- protective policies adopted by some exporting and importing countries (e.g. in the EU, CAP policies such as mandatory set aside regulation or production quota restrained supply. Furthermore, there was a change from price to income support and compensatory payments became decoupled, set aside was introduced and export subsidies were diminished. Some of these measures limited supply within the EU.)
- speculation.

The decline in agricultural production and corresponding available food stocks has been attributed to two main factors: the early effects of global warming, which has decreased crop yields in some crucial places, and a shift away from farming for human consumption toward crops for biofuels and cattle feed. Already "unusual weather events," linked to climate change such as droughts and floods have decreased production in important exporting countries. Part of the current problem is an outgrowth of prosperity. More people in the world now eat meat, and the increased demand for meat products means more grain is diverted from human consumption to animal feed.

Risks of low quality jobs

Although promises are being made that the production of biofuels will provide more jobs, there are risks that, given competition over land with peasant farmers, biofuel production may result in greater unemployment. In Brazil, it is estimated that 100 hectares dedicated to family farming generate at least 35 jobs, while 100 hectares dedicated to industrial farming of sugar cane and oil palm plantations provide only 10 jobs, and of soybeans half a job. As such if industrial farming takes over land formerly dedicated to family farming, the net effect will be fewer jobs.

South Africa expects to create as many as 55,000 jobs, mainly in the agricultural sector, through the use of biofuels. Annie Sugrue of the Citizens United for Renewable Energy and Sustainability (RSA) questions and disagrees with the employment figures in the South African Biofuel Strategy. She argues that the jobs the strategy expected the industry to create would be mostly low-level employment that would not create ownership for the poor rural communities in which the biofuels projects were located. She recommends that instead of using the current industrial model in which commercial farmers employ farm workers, South Africa should empower its rural poor by encouraging them to be producers in their own right rather than workers. There are reports where big companies enter into long-term leases for land with rural landowners and pay them very poorly for the land, instead of involving them in the projects and rewarding them appropriately.

11 ENVIRONMENTAL IMPACTS

11.1 Climate change mitigation

The environmental attractiveness of biofuels lies in their ability to substitute fossil fuels and the associated prospect of avoiding the release of fossil carbon in the atmosphere. This follows concerns about the long term impact of fossil fuel use, particularly climate change related greenhouse gas (GHG) emissions have become more pertinent as signals of climate change become more and more evident[10]. Although African countries only contribute 3% to global GHG emissions, the impacts of climate change will be worst felt in the region. Africa is more vulnerable to effects of climatic changes and least able to cope. Hence efforts to mitigate climate change will benefit Africa.

Biofuels have been promoted especially in OECD countries on the basis that they emit less greenhouse gases (GHG) than fossil fuels over their entire life cycle. Bioenergy can affect net GHG emissions in two main ways: (1) it provides energy that can displace fossil fuel energy, and (2) it can change the amount of carbon sequestered on land. However, the net carbon benefit depends on what would have happened otherwise, that is, both the amount and type of fossil fuel that would otherwise have been consumed and the land use that would otherwise have prevailed. GHG emissions of conventionally produced biofuels such as ethanol and biodiesel are critically dependent on manufacturing processes and the fate of by-products. In addition, the GHG balance is particularly uncertain because of nitrous oxide emissions from agriculture.

The potential environmental benefits of biofuel use needs to be confirmed and quantitatively specified along the whole supply-chain, including biomass production and conversion, and biofuel use. This is the purpose of life-cycle analyses (LCA). Estimating the net impacts of using biofuels and GHG emissions is a complex issue which requires, an understanding of fuel compositions, fuel production methods, combustion processes and related technologies throughout the full “fuel cycle”, from biomass feedstock production to final fuel consumption [IEA, 2004a]. Figure 15 compares the life cycle GHG emissions for bioethanol from various feedstocks. It is evident that the GHG balance for bioethanol from sugarcane is far more attractive than for example from maize.

The main GHG emissions in the biofuels are CO_2, Methane and NO_x. CO_2 is less problematic with biofuels since most of the CO_2 is assumed to be recycled during plant growth. For example, a full grown Jatropha Curcas shrub or tree absorbs around 8 kg of CO_2/year which can translate into CO2 sequestration of 20 tons/ha-yr (assuming a plantation with 2500 shrubs/ha) hectare (about 2.5 acres) [Muok & Källbäck, 2008]. Methane and oxides of nitrogen are more problematic and they come mostly from soil under cultivation and activities such as sugar cane burning.

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[10] An overwhelming body of scientific evidence indicates that the Earth’s climate is rapidly changing, predominantly as a result of increases in greenhouse gases caused by human activities (IPCC, 2001).

Emissions from the soil under cultivation are essentially nitrogen compounds associated with fertilizer decomposition and the main concern is with N_2O due to its high global warming potential (GWP-100). Several authors have tried to quantify these emissions and have found that they are highly dependent on soil conditions (moisture, nitrate, etc) and cultivation practices. Nitrous oxide originates from nitrification of ammonium and denitrification of nitrate. Seventy percent of global nitrous oxide emissions are associated with agricultural land use.

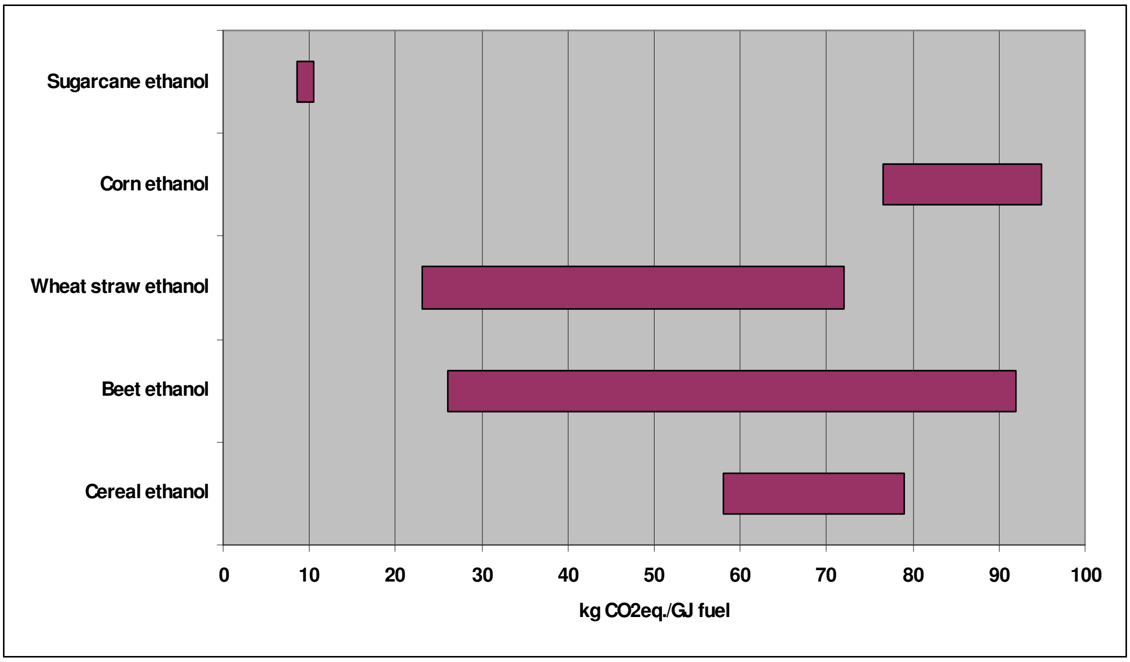


Figure 15: Comparison of GHG emissions from various ethanol biofuels
Source: Wamukonya, 2007.

Macedo *et al.* [2004] estimated that, under the Brazilian sugar cane cultivation conditions (applying 75 kg N/ha-yr for the cane cycle), the N_2O emissions are around 1.76 kg/ha-yr.

Lifecycle GHG balances

An assessment of the CO_2 lifecycle was conducted by Macedo *et al.* [2004] for the production and use of ethanol in Brazil, using a typical autonomous distillery as a model. The study considered carbon flows from three main energy process categories: direct energy consumption (external fuels and electricity), energy required for the production of chemicals and materials used in the agricultural and industrial processes (fertilizers, herbicides, lime, sulfuric acid, etc), and energy necessary for the fabrication, construction and maintenance of equipment and buildings. Apart from energy related carbon flows, N_2O from soil and CH_4 from cane burning were considered in the GHG balances. The study considered two scenarios: Scenario 1 reflecting the average conditions of a typical ethanol distillery and Scenario 2 representing the best distilleries conditions, in the Center-South region of Brazil.

Table 10 and table 11 summarise the GHG balances in terms of CO_2 equivalent. It shows that on average, ethanol production and use results in the emission of 34.5 kg CO_2 Eq/tonne cane.

Table 10: Ethanol lifecycle emissions (kg CO_2 equivalent/tonne cane)

Type	Scenario 1 (average)	Scenario 2 (best value)
Fossil fuels	19.2	17.7
Methane and N_2O from cane burning	9.0	9.0
Soil N_2O	6.3	6.3
Total emissions	34.5	33.0

Source: Macedo *et al.* [2004]

Considering ethanol productivities of 86.0 litres/tc and 91.8 litres/tc for scenarios 1 and 2 respectively, the avoided GHG emissions due to the use of fuel ethanol in Brazil are 2.6 to 2.7 tCO_2 Eq./m^3 anhydrous ethanol and 1.7 to 1.9 tCO_2 Eq./m^3 hydrous ethanol.

Table 11: Avoided emissions (kg CO_2 equivalent/tonne cane)

Type	Scenario 1(average)	Scenario 2(best value)
Surplus bagasse use	12.5	23.3
Ethanol use	242.5 (A); 169.4 (H)	259.0 (A); 180.8 (H)
Total avoided emissions	255.0 (A); 181.9 (H)	282.3 (A); 204.2 (H)
Net avoided emissions	220.5 (A); 147.4 (H)	249.3 (A); 171.1 (H)

Notes: (A)- Anhydrous ethanol; (B)- Hydrous ethanol; tc - tonne of cane

Source: Macedo *et al.* [2004]

LCA GHG emissions from biodiesel

Biodiesel is less energy-intensive than ethanol as the manufacturing process involves only relatively simple, low-temperature/low pressure steps. Thus energy related life cycle CO_2 emissions are much lower for biodiesel.

A US study, Sheehan *et al.* [1998] compares life GHG cycle emissions from biodiesel from soybeans and petroleum diesel when used in urban buses and shows that biodiesel's life cycle emissions of CO_2 are substantially lower than those of petroleum diesel. Biodiesel reduces net emissions of CO_2 by about 79% compared to petroleum diesel. For B20 blend, CO_2 emissions from urban buses drop by about 16%. In addition, biodiesel provides modest reductions in total methane emissions, compared to petroleum diesel. Thus, use of biodiesel to displace petroleum diesel is an extremely effective strategy for reducing CO_2 emissions.

However, the use of neat biodiesel (B100) in urban buses increases life cycle emissions of NO_x by over 13%. Blending biodiesel with petroleum proportionately lowers NO_x emission. For example, B20 exhibits a 2.7% increase in life cycle emissions of NO_x. Most of this

increase is directly attributable to increases in tailpipe emissions of NO_x. B100, for example, increases tailpipe levels of NO_x by 8.89%.
Furthermore, there is an increase in hydrocarbon emissions on a life cycle basis, although tailpipe emissions are lower. This is attributed to release of hexane in the processing of soybeans and volatilization of agrochemicals applied on the farm. Total life cycle emissions of hydrocarbons are 35% higher for B100, compared to petroleum diesel. However, emissions of hydrocarbons at the tailpipe are actually 37% lower. Obviously biodiesel from other feedstock result in different life cycle emissions.

Table 12 shows the average emissions from biodiesel compared to conventional diesel fuel. The general reduction in emissions with respect to biodiesel usage is evident from the table.

Table 12: Average diesel emissions compared to conventional diesel

Emission Type	B20 / %	B100 / %
Total Unburned Hydrocarbons	-20	-67
CO	-12	-48
CO_2	-16	-79
Particulate Matter	-12	-47
NOx	+2	+10
SOx	-20	-100
Polycyclic Aromatic Hydrocarbons (PAHs)	-13	-80
Nitrated PAHs	-50	-90

Source: Kiss *et al.* [2006]

In terms of best GHG balance the choice of the crop and the technology pathways play a key role. Net balance of CO_2 savings depends on the amount of energy used for cultivating, harvesting, transporting and converting the plants. It is important to note that for Jatropha production of Straight Vegetable Oil allows for maximum CO_2 savings as compared to conversion into biodiesel which involves large chemical inputs.

In addition, carbon credits from use of by-products can assist in increasing the GHG balance for biofuels. For example, sugar cane bagasse, the solid residue from sugar processing, can be conveniently used for firing boilers to provide process heat but more importantly to generate electricity which can be exported to the public grid. For biodiesel production, the application of the glycerine by-product can offset the manufacture of very energy-intensive chemical products substituted by the glycerine. Animal feed is the next most economic route (more valuable than fuel), but gives the lowest GHG savings.

Biofuel Life Cycle

Biofuels can have positive or negative impacts on various issues. In order to assess benefits from the utilization of biofuels compared to fossil fuels, life cycles have to be determined.

Life cycles largely depend on type of feedstock, choice of location, production of by-products, process technology and on how the fuel is used. Within this variety, the basic components of life cycles in biofuel processing are always the same. As it is shown in Figure 16, the life cycle of biofuels has several vertical process steps: biomass production and transport, biofuel processing, biofuel distribution and biofuel consumption. In addition, the industrial process steps of creating fertilizers, seeds and pesticides for the production of biomass must be included.

The life cycle is also influenced by horizontal attributes which have to be carefully assessed in order to allow comparisons among different biofuels: energy balance, emissions, greenhouse gas emissions, other environmental impacts, biofuel costs, and socio-economic impacts.

Argentina's soybean crop, which is mainly transgenic, threatens biodiversity in agriculture and hurts family farms and the rural social fabric, according to environmentalists and other critics. In the last decade, the expanding cultivation of soybean as the sole crop has prompted an exodus of seasonal workers and small farmers to the cities, while fuelling the concentration of land ownership.

The Argentine branch of international environmental watchdog Greenpeace has launched several campaigns to protest the deforestation of land rich in biodiversity by large soybean farmers.

Source: Valente, [2006].

A full grown shrub or tree absorbs around 8 kilograms of carbon dioxide every year. 2500 shrubs can be planted in a hectare (about 2.5 acres), resulting in more than 20 tons of greenhouse gas sequestration per year [Muok & Källbäck, 2008].

11.2 Competition for Land resources

Current biofuel crops are not efficient energy producers and require vast surfaces of arable land that will not be available for other purposes, such as food production. Other potential sources of bioenergy such as biogenic residues, and wastes are projected to contribute only 25-33% of future bioenergy supply. Hence, dedicated bioenergy crops are likely to dominate future biofuel systems, posing a huge demand on land. Because of anticipated shortages of land, there is a strong lobby for the development of C4 crops (trees and grasses) that are more efficient energy converters.

At current production rates of biofuels, the global arable land demand for biofuels remain small compared to total available land. This will obviously vary from country to country and decisions to grow energy crops for biofuels will have to take into account local context. Trostle [2008] examined land use in the top six biofuel producing countries and noted that despite rapid global expansion in biofuel production, total land cultivated in biofuel feedstocks amounted to about 19 million hectares in 2006/07, or only 3.4% of arable land in those countries. The US accounted for about 46% of the global total, followed by the EU and Brazil.

Scramble for land

There are fears that because of the need for land to develop large scale biofuel production systems, large corporate entities are likely to grab land at the expense of local communities and most likely in non-transparent ways. Because of rampant corruption in developing countries, proper procedures are unlikely to be followed in the allocation of land to large agro-businesses. As competition over land intensify, this will pit peasant farmers and indigenous communities against large agribusiness corporations who are already buying up large swathes of land or forcing peasants off their land. The Belgian human rights organization Human Rights Everywhere (HREV) has already documented forced evictions, the appropriation of land and other violations of human rights in the palm oil plantations in Colombia.

Lessons must be learned from the more recent expansion of soy production across Latin America, which has contributed to the deforestation of vast swathes of the Amazonian basin and has resulted in the forcible eviction of many peasants and indigenous peoples from their lands. The non-governmental organization FIAN International has documented the complicity of agro-industrial corporations, large landowners and security forces in forced evictions in Brazil, Colombia, Argentina, Paraguay and Indonesia. In some cases, agribusiness companies deceive peasants into selling their land, in others the companies occupy land without the consent of communities who have been living there for decades. In Paraguay, where the area planted with soy has more than doubled since the 1990s, many indigenous communities do not possess land titles and have been forcibly evicted. In Argentina, peasants and indigenous families have been evicted from their land while in Colombia, communities of indigenous people and people of African descent have been evicted from their land after oil palm growing companies occupied the land. Similar cases have been recorded in Indonesia and Cameroon [UN, 2007].

Competition for water resources

Agriculture is by far the biggest user of fresh water with world average of 70% of total human use, while industry and households consumes 20% and 10%, respectively [WWF, 2005]. Globally around 7130 km^3 of water is evapotranspirated by crops per year, excluding biofuel crops. Biofuel crops account for an additional 100 km^3 (1%). Total irrigation withdrawals amount to 2630 km^3 per year globally of which 44 km^3 (2%) is used for biofuel crops. It takes on average roughly 2500 litres of crop evapotranspiration and 820 litres of irrigation water withdrawn to produce one litre of biofuel. But regional variation is large [de Fraiture *et al.* 2007].

Biofuel scenarios project that energy crops will require an additional 30 million ha of cropped area (compared to 1400 million ha for food crops), 170 km^3 additional evapotranspiration (compared to 7600 km^3 for food) and 180 km^3 more withdrawals for irrigation (compared to 2980 km^3 for food). While for individual crops increases may be substantial, compared to the sum of all crops, increases are modest. These figures amount to increases in resource use of only 2-5%, levels too small to lead to major changes in agricultural systems at a global level [de Fraiture *et al.* 2007]. However local implications vary significantly across regions and countries.

For example, it has been estimated that by 2020 the water demand will exceed the availability in many parts of South Africa and over consumption and contamination are the major cause for that [Chessman, 2005]. Countries such as Pakistan, China, India, USA, Australia, Uzbekistan, Spain and Morocco have already reached or are close to the physical limits of renewable water resources in many of their regions.

Agricultural water use is a serious concern especially in arid and semi-arid regions, where water is scarce and highly variable throughout the year. An increase in irrigated land could lead to water scarcity, to the lowering of water tables as well as reduced water levels in rivers and lakes. Potential effects of increased water abstraction are salinization, loss of wetlands, and disappearance of habitats through inundation caused by dams and reservoirs.

11.3 Environmental concerns and deforestation

One of the greatest benefits of using biomass for energy is the potential to significantly reduce greenhouse gas (GHG) emissions associated with fossil fuels. However, one of the greatest risks is the potential impact on land used for feedstock production and harvesting (particularly virgin land or land with high conservation value), and the associated effects on habitat, biodiversity, and water, air and soil quality. Additionally, changes in the carbon content of soils, or carbon stocks in forests and peat lands related to energy crop production, might offset some or all of the GHG benefits.

A life cycle comparison conducted by Reinhardt [2008] of Jatropha Methyl Ester (JME) or Jatropha biodiesel with petroleum diesel is presented in Figure 16 with respect to GHG emission savings and other environmental impact categories such as energy use, acidification, eutrophication, and summer smog.

Jatropha biodiesel shows both environmental advantages (e.g. saving of non-renewable energy carriers) and disadvantages (e.g. acidification and eutrophication) compared to fossil diesel fuel. Therefore, according to Reinhardt [2008], an objective decision for or against a particular fuel cannot be taken. However, based on a subjective value system a decision is possible. If, for example, saving of fossil fuel and greenhouse gases is given the highest priority, Jatropha biodiesel performs better than fossil diesel fuel. An improvement of the impacts of JME can be achieved by the optimisation of the by-product utilisation.

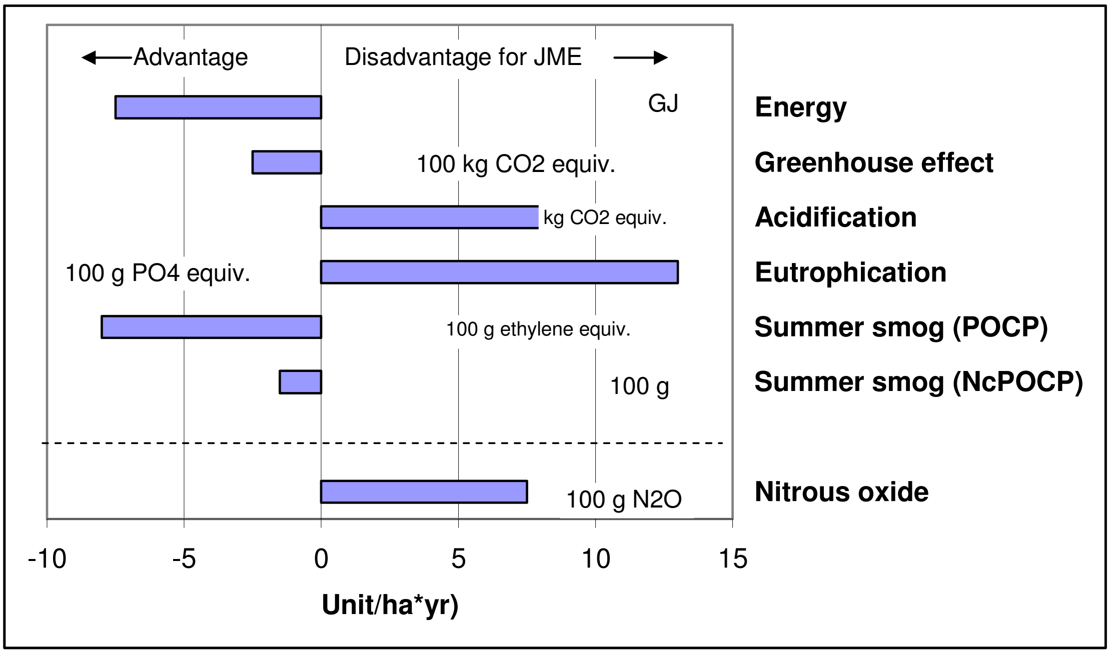


Figure 16: LCA comparison of JME and fossil diesel environmental impacts

Note: POCP - Photochemical Ozone Creation Potential
NCPOCP - Nitrogen-Corrected Photochemical Ozone Creation Potential

Source: Reinhardt [2008].

Mono-cropping

Large scale biofuel production typically requires use of large-scale mono-cropping which could lead to significant biodiversity loss, soil erosion and nutrient leaching. Most models of environmentally sustainable agriculture are based on multi-cropping rather than mono-cropping. Mono-cropping generally attracts pests and leads to selective nutrient depletion which demands the application of large quantities of pesticides, herbicides and chemical fertilisers. This leads to potential impacts such as eutrophication of water bodies, acidification of soils and contamination of surface waters (all of which are associated with nitrogen releases from agriculture), as well as loss of biodiversity and its associated functions. Finally the loss of pastoral lifestyles associated with shrinking grasslands, and the loss of feed production for domesticated and wild herbivores that depend on these lands, could have significant negative economic and social impacts.

Deforestation

Demand for biofuels could increase the pressure for deforestation. This can contribute to soil erosion, increase drought risks, and affect local biodiversity. In Africa, as in other regions, agricultural ecosystems can be complex and fragile. About 65% of total cropland and 30% of the pastureland in Africa are affected by degradation, with consequent declining agricultural yields. Soils are typically low in fertility and organic matter content, and soil fertility has been declining with removal of vegetation and overexploitation of land. Further, the use of scarce freshwater resources is a concern.

Ever-increasing swathes of virgin forest are being felled to provide cultivation space for biofuel crops. Thus a recent U.N. report predicts that 98 percent of Indonesia's natural rainforest will be degraded or lost within the next 15 years, in large part because of the planting of palm trees for the production of the biofuel palm oil. The same trees, for the same purpose, are devouring 0.7% of Malaysia's total rainforest annually. In China, the southwest region has been targeted for biofuels production but it coincides with the home of the last remaining intact natural forests. Even though these areas are regarded as degraded, they play an important role in biodiversity conservation.

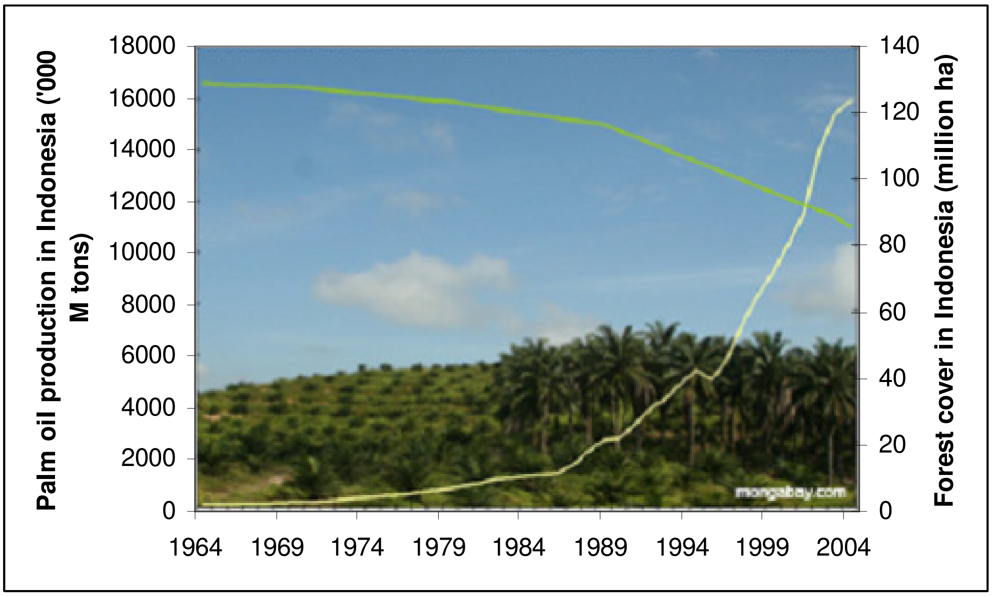


Figure 17: Linkages between palm oil production and deforestation in Indonesia
Source: FAO 2008

Indonesia lost 24.1% of its forest cover between 1990 and 2005. Since the end of the 1990s, deforestation rates have climbed by 26%. Rising deforestation rates have gone hand in hand with the expansion of oil palm plantations from 600,000 hectares in 1985 to 6.4 million hectares in 2006. The Indonesian government plans the conversion of another 20 million hectares in the next 20 years. Much of this expansion is happening at the expense of forests and peat swamps. The Borneo-Orangutan Survival Foundation have warned that palm oil expansion means the end for much of Indonesia's biodiversity.

Malaysia is the world's largest producer of palm oil and oil palm expansion has been accompanied by the largest increase in deforestation rates anywhere in the tropics. Large oil palm concessions have been granted in forest and peatland regions. Throughout South-east Asia, palm oil expansion and logging for timber are inextricably linked and both contribute to deforestation.

Risk of enhanced GHG emissions from land use change

There are concerns that biofuel plantations are replacing forests which are considered better carbon sinks than agricultural fields. According to The Gallagher Review [Renewable Fuels Agency, 2008], current LCAs of GHG-effects fail to take account of indirect land-use change and avoided land use from co-products. As a result there is significant uncertainty in GHG impacts of biofuel activities. A recent study by Wetlands International in conjunction with Dutch environmental consultancy Delft Hydraulics demonstrated that in Indonesia forest-burning for oil palm cultivation releases 33 tonnes of atmospheric CO_2 for every tonne of palm oil produced, ten times the amount released by a petrol-burning engine. Another study conducted by the University of Minnesota –USA claims that converting natural ecosystems to grow maize or sugar cane to produce ethanol, or palms or soybeans for biodiesel, could release between 17 and 420 times more carbon than the annual savings from replacing fossil fuels. The problem lies with the fact that landowners are rewarded for producing palm oil and other products but not rewarded for carbon management.

However, assessment of land use change impacts is rather complicated. This is a subject of current investigation by various research groups including the International Energy Agency. It is however, important to note that quantification of GHG emissions from indirect land-use change requires subjective assumptions and contains considerable uncertainty [Renewable Fuels Agency, 2008]. Especially, the role of co-products in avoiding land-use change requires further examination as such credits can improve the GHG balance of biofuels.

Water pollution

Inefficient use of agrochemicals such as herbicides and fertilizers can translate into water pollution that affect water quality and effluent run-off - whether the crop is irrigated or rainfed - and those associated with the water used in the fuel production chain in the industrial processing stage. Watercourses can be polluted by agrochemicals and sediments as well as downstream ecosystems.

For example, Mauritius sugar industry reported an annual input of agrochemicals of 65,000 tonnes of inorganic fertilizers and more than 360 tonnes of herbicides (a.i.) in sugarcane plantations. The concentrations of some herbicides was said to be in excess of tolerable limits in aquatic ecosystems. Analysis in experimental plots showed that diuron in the subsurface was very close to the environmental limits while for atrazine, the subsurface runoff showed concentrations over the limit after the first application.

Feedstock processing and fuel production also results in water pollution. For instance, sugar mills generate about 1,000 litres of wastewater per tonne of cane crushed. Sugar mill effluent from both cane and beet has a high BOD (Biological Oxygen Demand); effluents are also high in suspended solids and ammonium. This is the case for three sugar factories next to River Nyando in Kenya which led to decline in quality of source of drinking water to many families on its way to Lake Victoria, and nutrient over-enrichment of Lake Victoria.

11.4 Role of by-products: the case of Jatropha

Jatropha biodiesel shows both environmental advantages (e.g. saving of non-renewable energy carriers) and disadvantages (e.g. acidification and eutrophication) compared to fossil diesel fuel. Therefore, an objective decision for or against a particular fuel cannot be taken. However, based on a subjective value system a decision is possible. If, for example, saving of non-renewable energy carriers and greenhouse gases is given the highest priority, Jatropha biodiesel performs better than fossil diesel fuel.

An improvement of the impacts of JME can be achieved by the optimisation of the by-product utilisation. Figure 18 shows that with respect to the reduction of GHG emissions there is a large optimisation potential and best results are achieved if the by-products are used for bioenergy. Thereby, local production is not as effective as central production of JME.

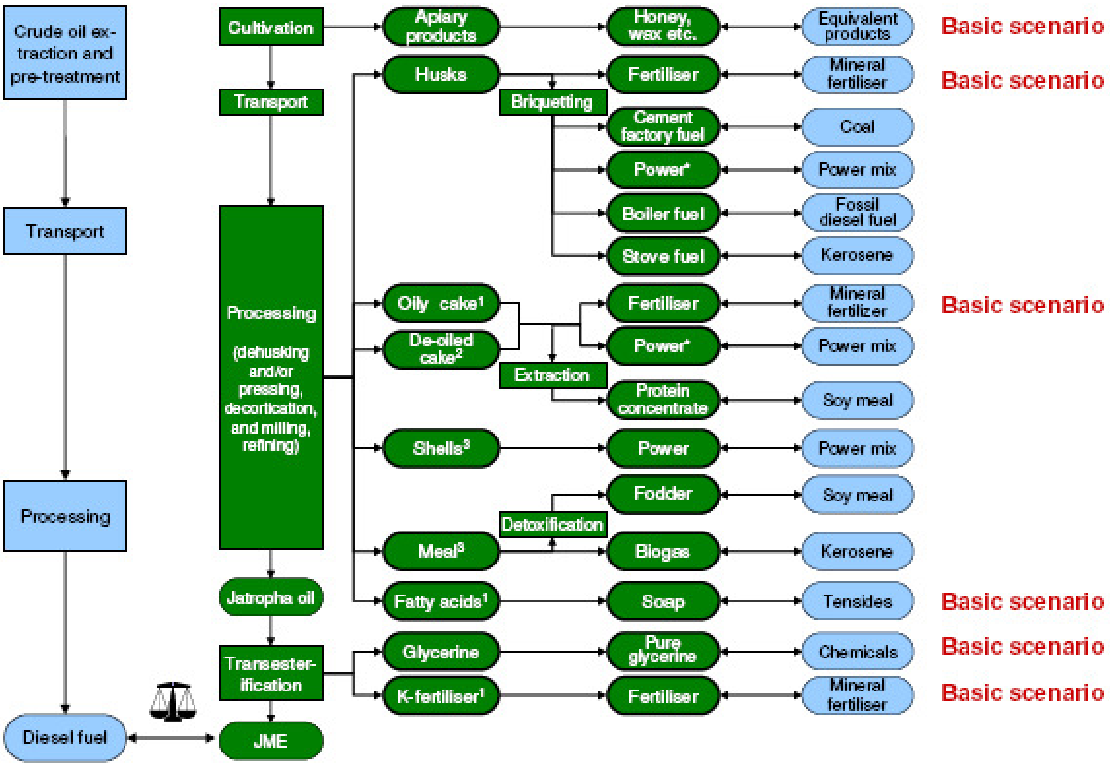


Figure 18: processes, by-products and end-uses in biodiesel production
Source: Reinhardt [2008]

Influence of Land Use Change on GHG Emissions

The level of GHG emission of JME production crucially depends of land use changes (i.e. carbon stock changes) involved in the cultivation of Jatropha. Cultivation of Jatropha on land with no vegetation gives a positive GHG balance from land use change whereas cultivation on land with medium vegetation gives a negative GHG balance from land use change. Thereby, JME may even have a worse GHG balance than diesel fuel.

Jatropha and Water Demand

Jatropha cultivation shows high yields if sufficient water is available. This fact, however, may lead to competition on land use especially when big investors are involved and large plantations are planned.

Summary

- Jatropha biodiesel shows both environmental advantages and disadvantages compared to fossil diesel
- If saving of fossil energy carriers and greenhouse gases is given the highest priority, the use of JME is advantageous
- Hence great optimisation potential
- Land use change: large influence on carbon loss / gain
- By-products / credits for bioenergy: bioenergy leads to higher savings depending on energy carrier replaced
- Conversion: centralised production more beneficial than decentralized
- Primary products: Jatropha oil and JME from centralised production comparable.

Recommendations

Establishment of new plantations

- Reduction of carbon stock must be prevented: plantations on poor, sparsely vegetated soils, e.g. degraded land, is best solution
- This also avoids land use competition with food production and minimizes risk connected to water availability

System optimisation

- Full potential of optimisation measures should be used: e.g. use of by-products for bioenergy generation.
- Jatropha production & use can be sustainable
- High potential for a sustainable low-input production and use of Jatropha oil especially for rural population.

PART B: IMPLEMENTATION AND STRATEGY

12 POLICY FRAMEWORK AND SUPPORT PROGRAMMES

12.1 Overview

There is a history of dependence of alternative energy technologies on government support to compete with fossil fuels at the marketplace. Biofuels are no exception. Biofuel programmes are essentially policy driven. Supportive government policies have been essential especially to the development of biofuels over the past three decades. A spectrum of policies which include explicit biofuel policies like excise tax exemptions, mandatory blending requirements, and renewable energy portfolio standards in transportation fuels and other indirect policies such as carbon policies, agriculture and trade policies, vehicle policies, etc., have influenced the evolution of biofuels. In general, countries use market regulation, through mandatory blends and economic instruments such as subsidies or taxes to support biofuel production and consumption. Table 13 gives a breakdown of the common policy instruments that have fostered successful biofuel production and use.

Table 13: List of policy tools and examples

Type of policy tool	Some examples
Incentive – Tax or Subsidy	Excise tax credit for renewable energy. Carbon tax, subsidies for flex fuel vehicles, price supports and deficiency payments, tariffs or subsidies on imports/exports, investment risk reduction for next-generation facilities, support for biofuel-compatible infrastructure and technologies, government guarantees and purchasing policies
Direct control	Renewable fuel standards, Mandatory blending, emission control standards, efficiency standards, acreage control, quotas on import/export
Enforcement of property rights and trading	Cap and trade
Educational and informational programs	Labelling, public education and outreach
Improving governance	Certification programs
Compensation Scheme	Payment for environmental service
RD&D	Crop research, conversion technology development, feedstock handling, etc;

Rajagopal [2008]

12.2 Economic policy instruments

Economic policy instruments are generally applied to encourage behavioural changes by making undesired behaviour choices unbearable and/or making preferred options more attractive. These instruments are usually employed in combination with regulatory instruments as well as communicative tools such as public education and outreach.

12.2.1 Fuel Tax Incentives

In most cases, the biggest barrier to widespread use of biofuels is the fuel retail. Fiscal support measures such as fuel tax incentives can therefore be a very effective tool for encouraging the use of biofuels, making them more price-competitive with petroleum fuels. Fuel excise tax reduction is the most direct and widely used instrument to help biofuels compete with fossil fuels. Most nations levy a tax on the consumption of petrol and diesel, and a fuel tax reduction for biofuels aims to lower the cost of biofuels relative to petrol or diesel [IEA, 2004a]. These incentives can be especially effective during the early years of fuel market development, as costs are expected to come down as the scale and experience of biofuel production increases. Since fuel excise taxes comprise a significant percentage of the fuel retail prices, exempting alternative fuels from a portion of this tax burden is a powerful tool for "levelling the playing field". This incentive also sends a clear signal to consumers regarding the relative social costs of different fuels.

In countries where fuel taxes are high because they are primarily for revenue generation, a fuel tax reduction adversely affects the fiscal situation. Governments are often concerned about reduced revenue from lowering biofuel taxes. This can be avoided by adjusting the taxes on all fuels so that total revenues are maintained [FAO, 2008 IEA, 2004a].

Biofuel tax policies vary widely in the level of reduction, the cap on production that is subject to reduction, the sunset clause, etc., across countries. For instance in the US, the volumetric ethanol excise tax credit provides a fixed tax credit of USD0.51 per gallon of ethanol blended with petrol (and USD1.00 per gallon for biodiesel). The level of exemption does not adjust to changes in oil prices and has no cap on production and no sunset clause. Tax credits, which are static in the face of changes in oil price, have no caps on production level or do not have a sunset clause, can result in a large increase in subsidy burden if there is a structural break resulting in lower oil prices or a large increase in biofuel production. For instance, Germany which had provided a total mineral oil tax exemption for biofuels in the past, has begun phasing out tax reduction for biodiesel starting in 2007 [Rajagopal, 2008].

Fiscal support measures have been important in promoting investment and use of biofuels in many countries. For example, the USA provides a variety of federal and state level incentives, including excise tax exemption and subsidies. Brazil provides support through credits for storing ethanol, a lower excise tax on ethanol fuel than on gasoline and investment concessions for new plant construction. The EU has issued a directive which allowed member states to exempt biofuels from fossil fuel taxes. France set production quotas along with tax incentives for biofuel production. In 2005, a progressive tax rate was implemented on petrol distributors to encourage blending biofuels with gasoline. Similarly, Spain, Germany, Italy, Portugal and Sweden all provided either partial or full exemptions from excise duties applied to petroleum products, along with laws to encourage biofuel production [FAO, 2006].

Similarly India introduced a Rs 0.75 excise duty exemption for ethanol sales in 2002 while China also provides subsidies for ethanol production. Tax incentives also apply in Thailand to promote an E10 mandate, while Australia, Canada and Japan provide investment and conditional production subsidies [FAO, 2006].

12.2.2 Carbon-based Fuel Taxes

A few countries have applied carbon taxes by taxing fossil fuels to make biofuels more competitive. For example, in Finland and Sweden taxation of oil has been in use since the 1970s as one of the means of reducing oil dependence. Finland is considered the first country to introduce a carbon based tax in 1990 while Sweden introduced it in 1991. As a result of such taxes, biomass became less expensive than coal in 1991 in Sweden and in 1997 in Finland [FAO, 2006]. Carbon taxes are taxes based on the carbon content of the fuel. These taxes make economic and environmental sense because they tax the externality (carbon) directly and are an effective way of addressing the polluter pays principle and increases government revenue. However, carbon taxes have the effect of driving fuel prices up, and are politically unpopular. Furthermore, while carbon-based fuel taxation is relatively straightforward, for biofuels to appear attractive it would be necessary to develop a scheme that takes into account well-to-wheels emissions, not just tailpipe emissions. This is a complex undertaking, because the scheme would vary considerably depending on how biofuels are produced.

Many countries have variable fuel or vehicle taxes based on carbon content or CO_2 emissions per kilometre driven. Sweden, Finland, Norway, the Netherlands and Slovenia tax fuels on the basis of their carbon content. But no country is known to take into account upstream emissions. In the case of biofuels, strong differentiation of fuel tax (or subsidy) based on well-to-wheels GHG emissions will serve to promote new, more environment-friendly biofuels such as cellulosic ethanol and biomass-to-liquids (BTL).

12.2.3 Vehicle Taxes and Subsidies

In addition to fuel-related incentives, fuel consumption can be affected by policies which encourage the purchase of vehicles running on certain types of fuel, or running on fuels that emit less CO_2. Denmark, the Netherlands and the UK have recently introduced new vehicle tax rates based at least in part on CO_2 emissions (though the Netherlands suspended their scheme after one year). For example, in the UK, the base vehicle registration fee is set at 15% for vehicles emitting 165 grams of CO_2 per kilometre driven. For each 5 grams additional CO_2 (depending on the rated fuel economy of the car), an additional one percentage point is added to the tax. For diesel, 3 percentages points are added. However, this approach provides little incentive to use biofuels since they have little effect on vehicle emissions of CO_2. The scheme would have to take into account upstream CO_2 for biofuels to receive a tax break [IEA, 2004a].

12.2.4 Emissions Trading

Under an emissions trading system, the quantity of emissions allowed by various emitters is “capped” and the right to emit becomes a tradable commodity, typically with permits to emit a given amount. To be compliant, those participating in the system must hold a number of permits greater or equal to their actual emissions level. Once permits are allocated (by auction, sale or free allocation), they are then tradable.

A well-functioning emissions trading system allows emissions reductions to take place wherever abatement costs are lowest, potentially even across international borders. Since climate change is global in nature and the effects have no correlation with the origin of carbon emissions, the rationale for this policy approach is clear. If emissions reductions are cheaper to make in one country than another, emissions should be reduced first in the country where costs are lower.

Emissions trading systems could include biofuels and create an incentive to invest in biofuels production and blending with petroleum fuels in order to lower the emissions per litre associated with transport fuels, and reduce the number of permits required to produce and sell such fuel. However, as for tax systems, in order for biofuels to be interesting in such a system, the full well-to-wheels GHG must be taken into account.

12.2.5 Incentives for Biofuels Infrastructure Investment

Apart from fuel-related incentives, an important barrier to the development of a market for biofuels is the required investment in infrastructure such as commercial scale production facilities. Fuel providers have little incentive to make large investments in these facilities in the uncertain markets. Even if governments put into place fuel incentives that generate demand for the fuel, investors will be wary that such policies can change at any time. In order to encourage the necessary investment, governments may consider certain investment incentives such as investment tax credits or loan guarantees.

Government funding for Research, Development and Demonstration (RD&D)

Linked to incentives for infrastructural development is support for RD&D on biofuel technologies has the potential to increase productivity and reduce costs. R&D has typically knowledge spillovers into the public domain and the private sector does not reap the full social benefits of their innovations. Hence government support for R&D investments is crucial.

Policies for flexi vehicles

Government policies have aimed to stimulate supply and demand for ethanol vehicles, through direct subsidies in the form of tax credits and indirectly through energy efficiency credits to manufacturers of automobiles. State and federal policies in United States and Brazil have given preference to alternative fuel vehicles, including FFV that can run on different blends of ethanol and gasoline. In the US, the Alternative Motor Fuels Act of 1998 has provided credits to automakers in meeting their Corporate Average Fuel Economy standards when they produced cars fuelled by alternative fuels, including E85.

12.2.6 Trade policies

Given the wide range of biofuels production costs worldwide and the wide range in production potential for biofuels in different countries, there appears to be substantial potential benefits from international trade in biofuels. However, a substantial specific trade regime applicable to biofuels is absent. Biofuels are treated either as "other fuels" or as alcohol (for ethanol) and are subject to general international trade rules under the WTO. They are generally subject to customs duties and taxes without any particular limits.

Most countries impose several forms of trade restrictions on both feedstock and biofuels, with preferential waivers of tariffs and quotas for certain countries. For example, import tariffs (and quotas) are omnipresent in most biofuel producing countries (See Table 14). These policies tend to protect domestic producers and restrict benefits to selected countries. Other countries tax exports, e.g. Argentina levies higher export taxes on soybeans and soybean oil and much less tax on biodiesel. This policy is meant to encourage the export value-added finished products rather than raw materials [IEA, 2004a; Rajagopal & Zilberman, 2007].

The ethanol market in several developed countries is strongly protected by high tariffs, and OECD countries apply tariffs of up to USD0.23 per litre for denatured ethanol. Some countries also apply additional duties to their tariffs, e.g. the US applies ad valorem tariffs of 2.5% for imports from most-favoured-nation (MFN) countries and 20% for imports from other countries. Japan applies ad valorem tariffs of 27% (MFN treatment) [IEA, 2004a; Rajagopal & Zilberman, 2007].

Farm policies

Since biofuel feedstocks are mainly agricultural crops and residues, and feedstock accounts for more than half of production costs, agricultural and trade policies that affect supply, demand and prices of agricultural commodities are important determinants of biofuel economics. Agricultural policies have tended to protect producers in developed countries from imports from lower-cost producers, while developing countries have tended to tax exports to fund government budgets. Through the farm commodity program, the US government pays a deficiency payment for eligible level of production to farmers who participate in feed grain programs. The deficiency payment is the difference between a target price and the market price, whichever is smaller. The effect in the biofuel market is to reduce the cost of feedstock and hence cost of biofuel.

12.3 Regulatory policy instruments

Regulatory mechanisms are employed to force desired behavioural changes and are especially useful where undesired behavioural consequences are severe. Unlike economic instruments, regulatory mechanisms often provide enforcement challenges.

12.3.1 Mandatory blending

These instruments allow government to exert direct control over fuel markets. Blending mandates are key to creating and guaranteeing a market for biofuels. In 2005-2006, several countries stepped up targets and mandates for biofuels. By the end of 2006, biofuels blending mandates existed at the national level in nine countries [REN21, 2009]. See Table 14 for a list of some of the countries with blending mandates in their policy portfolios. For bioethanol, mandatory blending ratios range from 2-25% depending on the availability of national production capacity and feedstock availability. Biodiesel blends are much lower in the range of 2 to 10%. In Africa, ethanol fuel has mainly been promoted by blending mandates. The US Energy Policy Act of 2005 mandates the production of 12 billion gallons by 2010 while the Renewable Transportation Fuel Obligation in the United Kingdom requires oil companies to blend 2.5% biofuel in motor fuel starting in 2008 and 5% in 2010-11 [Rajagopal, 2008].

12.3.2 Fuels Standards

In addition to mandatory blending legislation, some countries employ other regulatory mechanisms to accelerate the market transformation of biofuels. Fuel standards are one such mechanism employed by governments for influencing adoption of biofuels. Fuel quality standards are already being used to help protect public health and the environment from harmful gaseous and particulate emissions from vehicles and engines, and to help ensure compatibility between fuels and vehicles. Such standards have included a gradual phasing-out of lead to reduce the health risks from lead emissions from gasoline; measures to reduce fuel volatility so as to mitigate ozone, particularly in summer months; and standards which gradually reduce the level of sulphur content in fuels. By implementing a standard for minimum fuel content of non-petroleum fuel, governments could similarly use regulation to drive the market. This approach has the advantage of clearly defining the market share reserved for specific types of fuels, such as biofuels. It creates a stable environment to promote fuel production and market development. A disadvantage of this approach is that costs are uncapped, i.e. fuel providers must comply regardless of costs.

For instance, in the USA, the Clean Air Act and the Reformulated Gasoline Program legislation enforced the addition of oxygen to gasoline and created mandated or captive markets for bioethanol in the early 1990s. In 2005, MTBE was banished as an octane enhancer. The Energy Policy Act of 2005 also created a national Renewable Fuels Standard which set targets for ethanol fuel by 2012 and did not provide any liability protection for the use of MTBE. In 2003, the EU issued a directive for the use of renewable transport fuels with established targets and guidelines (Directive 2003/30/EC). It set the share of renewable fuels in total transport at 2%, rising to 5.75% by 2010 [FAO, 2006]. Through Directive 2008/0016 of 2008, the European Commission has updated its biofuel commitments. The Directive sets an overall binding target for the European Union of 20% renewable energy by 2020. In addition, it sets a 10% binding minimum target for the market share of biofuels in 2020 to be observed by all Member States.

Table 14: Summary of policies in various countries

Country	Biofuel Policies (explicit)	Main trade policy for biofuels
US	Export tax credit, mandatory blending, capital grants, vehicle subsidies	Import tariff of USD0.1427 per litre ethanol plus advalorem tariff with some exemption for Caribbean countries
Brazil	Mandatory blending, capital subsidies, vehicle subsidies	20% advalorem import tariff on ethanol (waived in case of domestic shortage)
EU	Excise tax credit, carbon tax credit, mandatory blending, capital grants and funding R&D	Advalorem duty of 6.5% on biodiesel and import tariff of USD0.26 per litre on ethanol (latter is waived for some categories countries)
China	Subsidies and tax breaks but only for no grain feedstock	Import tariff of 30% on ethanol
Colombia	Mandatory blending, tax breaks for sugarcane plantations, capital subsidies	Advalorem import tariff of 15% on ethanol and 10% on biodiesel
Indonesia	Mandatory blending, capital subsidies	Lower export tax for processed oils compared to crude palm oil
Malaysia	Mandatory blending, capital subsidies	Lower export tax for processed oils compared to crude palm oil
Thailand	Price subsidy, capital subsidies	Import tariff of 2.5 baht per litre and advalorem tariff of 5% on biodiesel
Canada	Mandatory blending, excise tax credit, capital subsidies	Import tariff of USD0.1228 for ethanol and USD0.11 for biodiesel (lower tariffs and exemption for select countries)
Argentina	Mandatory blending, excise tax credit, export tax exemption on biofuel blends	Low export tax (5%) for soy biodiesel compared to soy beans (23.5%) and soy oil (20%)
India	Mandatory blending, capital subsidies	Advalorem duty of 199% on CIF value of denatured ethanol and 59% duty on undenatured ethanol
Astralia	Producer subsidy, capital grants, vehicle standard	Import tariff of USD0.31 per litre on both ethanol and biodiesel
Japan	Excise tax credit	Advalorem import duty of 23.8% on fuel ethanol (to be lowered to 10% by 2010)

Source: Rajagopal, 2008

Sustainability Criteria and Certification

Sustainability criteria and certification schemes can help ensure that biofuels are sustainably produced, processed and transported. They give consumers - a means of distinguishing between sustainably produced biofuels from those that are not. For biofuels, the adoption of meta-standards could speed up their introduction where concerns about unsustainable practices (such as destruction of highly valuable ecosystems). The EU is already indicated in its Directive on biofuels that biofuel imports into the EU would be subject to strict sustainability criteria to trace if supply is sustainable.

For producing countries, sustainability criteria will ensure attainment of the benefits of biofuels (e.g. rural development) and to avoid negative environmental and social impacts. Both, small and large scale biofuel systems will be required for the future development of biofuels in Africa.

12.3.3 Vehicle Requirements for Compatibility

A non-traditional policy tool available to governments could be the introduction of vehicle technology standards that require compatibility with specific mixtures of biofuels. Brazil has essentially done this through a fuel standard, requiring all gasoline to be blended with 22% to 26% ethanol. This has forced manufacturers to ensure that their vehicles are compatible with these blends. In the US, and now in Brazil, several manufacturers have introduced flexible fuel capability in a number of vehicle models. Such vehicles can run on low or high-level ethanol blends, and the conversion cost (estimated at no more than a few hundred dollars per vehicle) is included in the vehicle price. If all new vehicles were required to be at least E0-E85 compatible, then ethanol could be used in any vehicle in any part of the world. Further, if all vehicles produced were of this type, the costs for producing such vehicles would probably drop considerably due to scale economies – perhaps to less than US$ 100 per vehicle above non-flex-fuel versions [IEA, 2004a].

Remarks

There is no single policy tool that is first best under all circumstances. The theoretical efficiency of any particular approach or tool depends on pre-existing distortions. In reality, actual policy depends on various factors such as budget and resource availability, information availability, transaction costs and political economic considerations. In most cases, countries use combinations of policy instruments to achieve desired outcomes such as market regulation (mainly mandatory blends) accompanied by economic instruments such as fiscal incentives to support biofuel production and consumption. In Africa, biofuel programmes have historically been promoted through mandatory blending in combination with price support mechanisms. For example, Malawi links the price of ethanol to petroleum prices to encourage ethanol production, in addition to providing market guarantees through blending.

A number of countries continue to adjust price regulation and modify tax incentives, as national biofuels targets and blending mandates continued to evolve. For example, in a concession to market realities, Germany lowered the mandatory biofuels blend rate for all transport fuels from 6.25% to 5.25% for 2009. The rate will again increase to 6.25% for 2010–14. All EU countries now have a biofuels target, most for 5.75% of transport fuels by 2010 rising to 10% by 2020. Some of the targets are just indicative. France has the highest target: 7% by 2010. India approved a new target of 20% biofuels blending in both gasoline and diesel over 10 years, along with tax incentives for growers of biofuels crops. The initial mandate was for E5 blending in 2008 but ethanol supply issues may have delayed that mandate. Countries with new biofuels targets include Australia (350 million litres by 2010), Indonesia (3% by 2015 and 5% by 2015), Japan (500 million litres by 2012), Madagascar (5% by 2020), and Vietnam (300 million litres by 2020).

In their initial stages of growth, biofuel programmes need government support, but as market matures and grows, costs are expected to come down with experience learning and biofuels become competitive. To avoid distortions and creeping of inefficiencies in the market, it is important to gradually reduce market support and allow market forces to act on their own. Generally some policy instruments need to remain in place to send the correct market signal and avoid relapse.

Biodiesel law in Argentina

Another regulation aimed at promoting renewable sources of energy, although oriented to agricultural transport and machinery, corresponds to the Biodiesel Competitiveness Plan (2001), which establishes the following benefits for biodiesel activities:

- Exemption from the so-called Fuel Transfer Tax (ITC = U$S 0.05/l for diesel oil) for 10 years
- A special arrangement concerning the capital gains tax, with an accelerated repayment for new investments
- Companies engaged in biodiesel activities are exempted from the alleged minimum capital gains tax, as from 1 January 2002
- Other provinces are invited to adhere to this legislation. The adherence should be accompanied by a compromise to exempt producers, storage and sales operators from the following for 10 years:
    - Gross income tax on industrialization and sales
    - Seals tax
    - Real Estate tax on biodiesel production and storage facilities

In addition, there is a feeling that this area has strategic importance, and, consequently, many decision makers have shown interest, such as both Congress chambers, local authorities from the Santa Fe, Cordoba and Entre Ríos provinces, and the Grains Stock Exchange. There are also specific financial instruments for the promotion of biodiesel and a certain degree of competition between local governments to attract investors, although they are working towards promotion at national level. As a result of these promotion measures, there are in Argentina several projects for biodiesel production, 17 of which are already in sporadic operation. However, further development is prevented due to the lack of adequate incentives.

In opposition to what occurs with gasoline, Argentina has no Gas Oil surplus and some supply problems have been experienced in the agricultural sector which resulted in the import of gas oil.

Hence, the production of biodiesel based on local raw materials would be very convenient and a concrete opportunity for de-centralizing its production using portable equipment.

Source: Bravo, *et al* [2005]

13 KEY LESSONS LEARNT

Assessment of Local Needs, Development Potential and Constraints

Prior to introducing fuel crops it is important to analyze traditional fuel consumption patterns, costs of (traditional) energy sources, and the share of household income spent on fuel to meet energy needs. Land ownership also must to be part of the assessment. The question of whether rural households or specific target groups own land or can obtain the rights to use land for energy crop cultivation is of critical importance to the success and sustainability of biofuel projects, in Sub-Saharan Africa, as well as elsewhere.

Before introducing any new crops, including energy crops, it is important to conduct field research to identify those crops that are genuinely suitable for the area and local conditions. Perennial crops may be easier to grow than annual crops (e.g., jatropha, moringa tree, croton, pongamia, palm oil, etc.). They require less care after the initial years and less labour (with the exception of harvesting). Crop selection should also consider the seasonality of the plant, local climate, quality of soil, water availability, local ecosystem, skills of the local population and land availability.

A decision to produce biofuel opens up a choice between biodiesel and bioethanol. Biodiesel production lends itself better to small scale processing as most perennial biodiesel crops can be grown on marginal land, and they require less care compared to crops grown for producing bioethanol. Crops for biodiesel production can be processed for several other uses resulting in by-products such as fertilizer, medicine, or soap.

Social Development

In rural areas, biomass collection to meet energy needs is largely undertaken by women and girls who spend many hours each day collecting fuelwood, and incurring risks of accidents, assaults and animal bites. Fuel collection is time-consuming and reduces the valuable available time for educational and income-generating activities. Moreover, women have less access than men to credit, land ownership and training that are necessary for improving energy access to support livelihoods and for income generating activities such as micro-enterprises. Analyzing the social aspects of a project can be of crucial importance to the success or failure of any rural development initiative in Africa, including biofuel development.

Agricultural Extension Services and Capacity Building

Local needs and potentials are essential when selecting the appropriate technology for biofuel development. Capacity building involves various aspects, ranging from training of farmers to selection of feedstock, or to the transfer of technical skills for artisans and blacksmith in order to maintain equipment, transfer managerial and financial skills, and train rural women. Specific skill needs include information on high yielding plants, marketing expertise, building the local base for cooperatives, access to inputs (e.g., seeds, fertilizer, etc), and support across the value chain.

Agricultural extension services and/or rural community support services play an important role in supporting farmers to obtain seeds, tools, financing and marketing support. These services should be expanded wherever new crops or production techniques are proposed to be introduced.

Policies

A range of policies are available to support sustainable small scale biofuels production. These include both market push policies aimed at increasing biofuels supply, market pull policies which seek to increase biofuels demand, and mega policies including feed-in tariffs (set a long term price for biofuels) and renewable portfolio standards (require a set aside purchase for biofuels in the market).

Fiscal policies and their implementation determine the economic feasibility of fuel crop cultivation to a considerable degree. The feasibility of investment in fuel crop cultivation and biofuel production increases with prices of the alternative fossil fuels in the various local markets.

Whereas relative price subsidies for diesel fuels or kerosene may narrow the scope for domestic biofuel production and marketing in developing countries, taxation of these fossil fuels could raise price levels and provide incentives for fuel crop cultivation. However, any fiscal policy intervention needs to be carefully designed and calibrated.

A number of factors should be considered in establishing biofuels policies. These include sustainability criteria for local development/use, policies and regulations to protect small farmers from investors and large scale agro industries, fair trade practices, and linkage of biofuels to other sectors. Promotion of national centres of excellence will also be important.

Financing

Biofuel projects, even small-scale projects, require investment and financing. Communities in Sub-Saharan Africa face many constraints and barriers regarding access to adequate finance, such as capital availability, resources, infrastructure and technology.

It has been generally acknowledged that the public sector in many developing countries will not be able to finance all the investment needed to satisfy growing energy demand requirements. Thus, it is important to work with private investors (local and international), multilateral institutions and development assistance agencies in order to mobilize necessary technical support and the financial means necessary for project implementation.

Setting Indicators

Following the completion of any assessment, it is important to set up baseline economic, environmental, technical and social indicators to measure project performance.

Bottom-up Approach

Grassroots initiatives and the active involvement of targeted communities are essential for project success. Rural development projects involving production and use of liquid biofuels will likely be more sustainable if communities have been involved in the planning process, if all required inputs are secured and made available, and if all new income generating opportunities are effectively used.

Lessons Learnt

The following lessons were learnt during the implementation of the FACT projects in Mali, Mozambique and Honduras.

Garalo Project in Mali

- High quality seeds are important when starting Jatropha plantations: clonal and seed gardens are key tools for the local production of high quality seeds.
- Direct seeding is giving good results under conditions of a 3 to 4 month rainy season. Nursery efforts and costs can thus be avoided.
- Good yielding Jatropha requires good nutrient levels and climate conditions.
- Food and Fuels can be combined with good nutrient levels and produce more than food alone under current practices.
- Generator technology: marine generator sets do better than automotive based generator sets. This is a key to the success of the Garalo project.
- Electricity distribution: new methods of payment as a result of discussions in the project: in a first test the regular monthly payment might be replaced by the payment in kind (e.g. with livestock) for a longer period.
- The prescribed minimum local electricity tariff is key factor in economics of the project: Jatropha based generation is more expensive than current electricity tariff, but cheaper than diesel based generation.
- The Garalo project is highly replicable: in neighbouring villages replication was studied using participatory village discussions: a program was prepared for 10 villages.

Project Mozambique

- Introducing bio-fuels requires careful imbedding in the local situation. Farmers Clubs, proved to be most important actors in the project.
- The combination of food crops and Jatropha is a “condition sine qua non” for smallholder farmers. Placing Jatropha fences around vegetable fields, animals are kept out, while the food crops ensure maintenance of Jatropha.
- Project duration of three years is generally too short. Best 5 years in order to obtain sufficient yield of the Jatropha plant.

- Long time controlled endurance tests (Netherlands) for PPO fed diesel engines are required before introduction in the field.
- The quality of oil is to be controlled during in whole production chain, from plant production to distribution. For example: harvesting green unripe seeds results in too high phosphor contents, bad for diesel engines.
- Comprehensive identification of pests and diseases in Jatropha Curcas was needed. Jatropha contrary to the myth can be affected by numerous pests. Involving the local R&D institutions (the Eduardo Mondlane University), has proved to be effective.
- Jatropha Curcas does not need shaded nurseries when sufficient water is available.

Gota Verde Project in Honduras

- Apart from Jatropha, many other oil crops were tested in Honduras and found attractive as producer of oil for energy purposes and for other uses.
- Biodiesel production was tested and best practice information on the process on semi industrial scale available as open source.
- The feasibility of Jatropha cake for biogas for electricity generation was studied and found highly attractive: a factor 3 less costly as with PPO.
- Replication biogas from cake: use of press cake is pursued in 3 other projects in Tanzania, Kenya and Indonesia, power plants of 150, 150 and 200 kWe capacity.
- An innovative system using energy pastures in the tropical humid zones for energy was developed and will be tested in the Gota Verde project.

General Lessons Learned

- Projects to be based on realistic (lower) estimates of yield potential of the selected crops.
- Good genetic starting material (seeds) of the biofuel crops is crucial and comes at a price.
- Intercropping of food and fuel crops is useful for fuel crops that take several years to mature, such as Jatropha. Intercropping ensures income for the farmers from the start of the project and helps to suppress weeds.
- Maximum value should be obtained from the agricultural production chain. A bio-refinery approach should be practised where feasible, aiming to bring maximum value of all components of the plant.
- The project area is best to avail over basic development needs (schools, medical care, markets, demand for energy), with agriculture beyond subsistence level, and farmers are eager to experiment with new cash crops.
- Presses: thanks to R&D at TU Eindhoven and at Wageningen University much new knowledge is generated about the technology for pressing seeds.

Source: Rijssenbeek [2008]

14 SYNTHESIS OF BEST PRACTICES AND APPLICABILITY: JATROPHA

14.1 Jatropha cultivation

Aiming mainly at oil production, block plantations are probably the best option. How such plantation is best established, is subject to much discussion yet. According to Heller [1996] plants propagated by seeds are preferred for establishment of long living plantations for oil production. This can be supported by the fact that vegetative propagated plants do not develop a tap root, but only a superficial root carpet, which leads to more superficial water and nutrient competition. The tap root of generatively propagated plants will have more access to nutrients from deeper soil layers and can reach deeper water resources.

The selection of basic material is a critical step (in case of vegetative as well as generative propagation). Basing this selection on successes of controlled breeding programs would be the best option, but present results are not yet sufficient. In JCL provenances available in India only modest levels of genetic variation were observed, while wide variation was found between the Indian and Mexican genotypes. This shows the need to characterization of provenances with broader geographical background. Best available practice at the moment is to use planting material obtained from the best performing trees of the best performing provenance available in the location of interest. Trees with an annual yield above 2kg dry seeds and seed oil content higher than 30% by weight can be considered a good source. In generative propagation the selection of the heaviest and largest seeds for sowing results in significant growth increase of JCL seedlings. Although germination rates, certainly after easy applicable pretreatments of the seeds (nicking, cold water), are quite high and although nursery Bags can hamper initial root formation, we would intuitively recommend plantation establishment through planting of seedlings. As such the plants can be sufficiently protected in their initial growth stage, when they are still quite susceptible for weather extremes or other possible events. Using seedlings one has more control on the uniformity of the plantation as well. Further the planting pits will guarantee a good establishment in the soil. The main draw back of this practice is the influence of the polythene bags and pots on the root structure.

Due to root competition for water the optimal spacing is believed to be a function of rainfall, where wider spacing should be used in semi-arid environments and denser plantations can be appropriate for sub-humid environments. It was noted that spacing of plants is a trade-off between biomass and fruit production. A narrow spacing will lead to fast canopy closure which results in higher water and light competition and lower fruit: biomass ratio in the mature stadium. When planting JCL for live-fencing or hedges for soil conservation a dense biomass is needed and close spacing is appropriate. When the aim of the plantation is oil production, seedlings should be planted wide enough to ensure high seed yields in the mature stage, but close enough to avoid unacceptable loss of photosynthetic capacity in the juvenile stage. Thus, optimum spacing can only be recommended after at least 5years consecutive growth and yield observation sand this in different environmental conditions and using different provenances. The authors feel that the best available practice at this moment is to start with a densely spaced block plantation and gradually remove rows or individuals (thinning) according to the plant performances.

Contrary to popular believe, it should be made clear that plantations aiming at oil production will need fertilization (artificial or organic). Fertilizer at least needs to compensate the nutrient removal due to harvest or management practice (pruning—if not used as propagation material). Irrigation will depend on the climatic conditions of the location. The minimum annual average rainfall at which JCL is known to yield a harvestable amount of seeds is 500–600mm/yr. So, simultaneous reclamation of barren lands and bio-diesel production will inevitably imply use of fertilizer and irrigation. Although there are already several fertilization trials available there is still insufficient information to account the nutrient need for specific environmental and genetic setups. The same applies for irrigation.

Reliable yield prediction still forms the biggest problem. At present there are no reliable field data on the dry JCL seed yield per ha per yr in a given set of conditions and at a certain level of input. It is believed that for well-managed plantations in good environmental conditions a yield expectation of 4–5 t dry seed/ha is reasonable. In order to tackle this Knowledge gap, it is absolutely necessary to systematically monitor the year-to-year seed yield in operational plantation conditions along with the influencing factors. Furthermore, research is necessary to quantify the causal effects of each of the influencing factors on the yield. It is important to give special attention to the interactions between the environmental and management requirements and the influence of the different provenances. Issues to address at the crop level are biogeochemical cycling, water use efficiency, drought resistance, total biomass production, pest management (inclusive hosting and transmitting capacity of pest and Diseases infesting other crops), issues on invasiveness and land suitability of JCL.

JCL is still a wild plant with a wide variation in growth, production and quality characteristics. In order to work towards high yielding bio-diesel plantations, the best suitable germ plasm has to be identified for different cultivation situations. This implies characterization of provenances with broader geographical background in order to widen the genetic base of JCL. An intensive inventory of the finalized and on going provenance trials will give an idea of the available material and will indicate where more provenance trials are needed (this is ongoing in the global Jatropha Curcas evaluation, breeding and propagation Program of Plant Research International, Wageningen). Based on such information, systematic and selective breeding should be carried out in order to develop high and early yielding hybrids with high oil yield in given site conditions. Recently a method has been developed for identification of superior lines by assessing the phenotypic traits of JCL plants recorded in situ. According to the authors this method facilitates the selection of promising accessions for multi-location evaluation and hastens the process of utilization of germplasm. In short it can be stated that more systematic research and complete reporting is necessary on the input-responsiveness of the production at different levels of inputs, including environmental, as well as genetic, physical, chemical and management inputs (e.g. spacing, soil conditions, pruning, fertilizer, irrigation).Seed yield and biomass production in different environmental and abiotic setups, using different provenances or accessions, applying different levels of the different inputs should be monitored in order to discover the input-responsiveness of those different inputs as well as the interactions between the different inputs and the interaction between the environmental and genetic setups and the different inputs.

14.2 Oil extraction

The choice of extraction method is clearly dependent on the intended scale of the activity. The two extraction procedures, mechanical and chemical, are quite well established, although there is still scope for further research. Both of them have their advantages and disadvantages with respect to scale suitability, centralization, extraction efficiency and environmental and health risks. Further research should investigate efficiency improvement of mechanical oil extraction, the applicability of alternative solvents as supercritical CO2, bio-ethanol and isopropyl alcohol and their economical viability. Decentralized processing technology should be considered as well. Such development should go in synergy with the transesterification setup. The seed/kernel cake is a very important by-product, which we recommend to be brought back on the JCL field. Although the use of the cake as fertilizer is already common practice, there are still questions to be addressed. More trials are needed where the growth effect on different kinds of crops are monitored(including phytotoxicity and bio-safety effects). The impacts on the soil structure, water-holding capacity, soil decomposition, organic matter content and soil biological activity should be brought under detailed investigation as well.

14.3 Production and use of Jatropha biofuel

The production of bio-diesel from vegetable oils in general is well documented. Crucial research and development options lay in the maximization of the transesterification efficiency at minimal cost. An important issue in this is the improvement in the catalytic process, certainly the recovery and there use of the catalyst. As part of the option of decentralized processing units, low-cost, robust and versatile small-scale oil transesterification designs should be developed. The choice of using JCL bio-diesel (i.e. methylesters) or the JCL oil depends on the goal of the use (e.g. electricity or transport) and the available infrastructure. Studies show that transesterified JCL oil achieves better results than the use of pure JCL oil, straight or in a blend, in unadjusted diesel engines. Changing engine parameters shows considerable improvement of both the performance and the emission of diesel engines operating on neat JCL oil. More trials on the use of straight JCL oil in different diesel engine setups should be tested and investigated. Accurate measuring and reporting on emissions contributing to global warming, acidification, eutrophification, photochemical oxidant formation and stratospheric ozone depletion is very relevant. The long-term durability of the engines using bio-diesel as fuel requires further study as well.

15 POTENTIAL IMPLEMENTATION BARRIERS/CHALLENGES

Feedstock awareness

The choice of feedstock from which to produce small-scale biofuels is an important issue; however there is limited African experience to date. If the availability of oil seeds varies from year to year, small-scale production can be affected, especially when seed collection remains in the informal sector. Establishing local storage could provide a buffer against supply vagaries.

Biofuel production using edible crops is not suitable for most conditions in Sub-Saharan Africa due to concerns about food security and competitive use of agricultural land. Use of straight vegetable oil/pure plant oil can greatly simplify the use of biofuel as a transportation fuel since it renders the transesterification process and involved technology and costs unnecessary. Successful engine trials with raw pongamia oil in India and jatropha oil in Mali over a period of two to three years have been reported. However, long term impacts on engine performance and maintenance problems remain to be studied [UNDESA, 2007].

Land ownership

Land ownership patterns vary from country to country. Land owned by government, forest land, land under custody of village council as common property, and privately owned are the main categories. With considerable incomes being generated by biofuel cultivation, the issue of competitive use of agricultural land will become increasingly relevant as land used for agriculture and cash crop might get diverted for biofuel cultivation.

Policy support

Within sub-Saharan Africa, there are a lack of policies to support small-scale biofuels development at the local level, including fiscal and financial incentives and provision for SME fuel blenders. In cases where biofuels policies do exist, they tend to focus on subsidies for large industrial biofuels producers, with smaller scale farmers mentioned as providing crop inputs for these larger operations. The potentials for biofuels development to meet local energy needs have not as yet been widely recognized.

Policies are needed to ensure that local households, businesses, and communities capture the benefits of energy services afforded from biofuels development, as well as associated income and job opportunities. Policies should be long term, stable, and clear, and ensure biofuels development by local people, for local people. To ensure effective policy promotion, government decision makers will need to engage small farmers and producers in the policy formulation discussions.

Policy support will need to consider a range of issues including production, logistics, linkages, outreach, technical assistance, end user acceptance and pricing.

Affordable financing

A key barrier to small-scale biofuels development is access to affordable financing. This is required by small farmers who need working capital for the purchase of seeds and equipment as well debt and equity financing to build biofuels businesses. Consumers may also require credit to purchase biofuels for their household or business needs at terms and conditions matched to their ability to pay.

Institutional capacity and awareness

Currently in Sub-Saharan Africa, there is a lack of awareness of the opportunities of small-scale biofuels, as well as the capacity to develop these programs and projects. This includes a lack of capacity in the public sector (regional, national, and local) for the development of effective policies to promote small-scale biofuels development; with the private sector, including small farmers, to design, develop, implement, and operate these projects; among consumers who lack information on the costs and benefits of these technologies; and with local NGOs, credit providers, market intermediaries financiers, and others, all of which have a significant role to play in the development and advancement of small-scale biofuels. Each of these groups will require capacity building and support to develop small-scale biofuels potential in sub-Saharan Africa. Moreover, more effective coordination and cooperation between these various stakeholders will be important.

Local technology production

In sub-Saharan Africa, there is a lack of locally available, locally produced biofuels technology, products, and equipment. Local developers may be not be aware of the available product offerings in the marketplace and how to obtain these, and foreign technology can be difficult to procure and expensive to purchase. Development of local technologies, products, and services matched to the needs of the marketplace will be important of the scale-up of small-scale biofuels throughout sub-Saharan Africa.

Market development

To develop small-scale biofuels in the region, it will be necessary to understand the market needs and establish effective supply chains for product delivery, servicing, and financing. A key requirement is the need for effective business models for biofuels development.

A host of operational issues will need to be considered across the value chain including: soil characterization, plant/feedstock selection, seedling supply arrangements, post-planting care/management, inter/multi cropping (very important to improve economics by extending the planting season and diversifying crop base), outreach to local communities, blending arrangements, safety and environmental safeguards, and risk management, etc.

Among all the oil bearing crops, Jatropha Curcas (JC) has emerged as the focal point for the biofuel industry with rapid R&D investments flowing into its cultivation, processing and conversion into biodiesel [Rajagopal, 2008]. However, despite its appeal and potential, large-scale planting of jatropha is still a risky proposition, since few scientific details are known about the plant.

According to Rajagopal [2008], experiences across the developing world with JC have been quite varied reflecting complexities in local practices, soil, water and climatic factors.

It has also become clear that the positive claims on JC are numerous, but that only a few of them can be scientifically sustained. The claims that have led to the popularity of the crop, are based on incorrect combination of positive characteristics, which are not necessarily present in all JC accessions, and have certainly not been proven beyond doubt in combination with oil production. Hard figures and verifiable data on various aspects of JC remain scarce.

A major constraint for the extended use of JC seems to be the lack of knowledge on its potential yield under sub-optimal and marginal conditions. This makes it difficult to predict yields for future plantations under sub-optimal growth conditions, the conditions where JC is especially supposed to prove its value [Jongschaap *etal.* 2007].

Despite the potential qualities of JC as a sustainable feedstock for biofuel there are specific issues pertaining to translating it into commercial and social benefits that remain uncertain. Jatropha projects are very location specific and it has been noted that experiences are not transferable across borders [Rajagopal, 2008]. JCL is still a wild plant with a wide variation in growth, production and quality characteristics [Achten *et al.* 2008].

The traditional and successful application of JC includes functions like soil water conservation, soil reclamation, erosion control, living fences, firewood, green manure, lighting fuel and local use in soap production, insecticide and medicinal application at modest scale. However, according to [Jongschaap *et al.* 2007] claims of high oil yield production from JC are not backed up by any scientific findings so far (especially not at a large scale), and therefore should be regarded with caution. Especially the claims of low nutrient requirements (soil fertility), low water use, low labour inputs, the non existence of competition with food production, high oil yield and tolerance to pests and diseases are definitely not true.

Contrary to popular believe, it should be made clear that plantations aiming at oil production will need fertilization (artificial or organic). Fertilizer at least needs to compensate the nutrient removal due to harvest or management practice (pruning-if not used as propagation material). Irrigation will depend on the climatic conditions of the location. The minimum annual average rainfall at which JC is known to yield a harvestable amount of seeds is 500–600mm/yr, and shows the effect of limited water availability on JC plant growth. Simultaneous reclamation of barren lands and biodiesel production will inevitably imply use of fertilizer and irrigation. Although there are already several fertilization trials available there is still insufficient information to account the nutrient need for specific environmental and genetic setups. The same applies for irrigation [Achten *et al.* 2008].

Developing sustainable Jatropha projects do pose challenges of varied nature and some critical ones are discussed below.

Agronomic challenges

Plant agronomy poses key challenges to the viability of Jatropha projects and key among them is the diversity in Jatropha types in each region. In most Jatropha driven regions there exists a wide variety of Jatropha plants. Each of these is defined by differences in oil content, yields, maturity periods, resistance to drought and pests, and rainfall requirements.

It is critical to make the right choice of Jatropha type for any given region and assess its overall suitability to ensure long term sustainability.

Technological challenges

Existing technological utilities for Jatropha needs closer attention. Most technologies for biofuel have been based on rape seed or palm. However, very few of these technologies have been extended for Jatropha. There is a need for further research on process technologies and design of equipment to scale up the Jatropha projects.

Finance barriers

A major challenge for Jatropha projects is related to financing options available. Today, there is widespread reluctance on the part of financial institutions of all hues and shapes to approve projects related to crops and it is necessary to sensitize regional and international financial institutions on the economics of Jatropha. Jatropha start up have a 3 year gestation period before the first significant harvest making it a risky investment.

Policy barriers

In countries where Jatropha based biofuel could be produced, there is often a lack of appropriate policy support to small-scale Jatropha development at the local level.

Policies are needed to ensure that local households, businesses, and communities receive the benefits of energy services from Jatropha based biodiesel development, as well as associated income and job opportunities. It is essential to engage small farmers and producers in the policy formulation discussions.

Policy support will need to consider a range of issues, These are:

- Feedstock production methods, transformation Jatropha biofuel quality standards and testing
- Ensuring quality product
- Evolve guidelines for suitable available technology, logistics, etc
- Pricing mechanism
- Incentivise biofuels usage
- Favourable tax regimes
- Capacity building in executive bodies

16 IDENTIFYING MARKET BARRIERS AND DESIGNING RESPONSES

The promotion of renewable energies is faced by various market barriers. These barriers limit the development of renewables unless special policy measures are enacted, unless no other fossil resources are available or unless the price advantage of renewables highly exceeds that of fossil fuels. In order to promote a fast introduction of biofuels, barriers have to be detected and solutions have to be found. The Union of Concerned Scientists formulated four main categories of barriers to renewable energy technologies (RET):

- Barriers faced by new technologies competing with mature technologies
- Price distortions from existing subsidies and unequal tax burdens between renewables and other energy sources
- Failure of the market to value the public benefits of renewables
- Others, e.g. inadequate info, lack of access to capital, high transaction costs

These barriers to RETs also apply to biofuels. In order to find solutions for overcoming these barriers, they have to be described in more detail. The main market constraints specific to biofuels can be summarized by nine main market barriers:

1. Economic barriers: The production of biofuels is still expensive, markets are immature and beneficial externalities are not accounted.
2. Technical barriers: The fuel quality is not yet constant and conversion technologies for certain biofuels are still immature (e.g. for synthetic biofuels).
3. Trade barriers: For some biofuels still no quality standards exist. Also no common European sustainability standard exists. Barriers exist for international trade of bioethanol due to denaturation obligations.
4. Infrastructure barriers: Depending on the type of biofuel, new or modified infrastructures are needed. Especially the use of biohydrogen and biomethane need profound infrastructural changes.
5. Chicken and Egg dilemma: Before owners of filling stations sell biofuels, they claim that car manufacturers have to sell refitted cars first. The automotive industry claims that the infrastructure has to be developed first. This is a visible barrier for introduction of FFV and promotion of E85 in some European countries
6. Ethical barriers: Biomass feedstock sources may compete with food supply.
7. Knowledge barriers: The general public, but also decision makers and politicians are lacking knowledge on biofuels.
8. Political barriers: Lobbying groups influence politicians to create or conserve an unfavourable political framework for biofuels.
9. Conflict of interest: Conflict between ‘promoters’ of first and second generation biofuels may weaken the overall development of biofuels.

Above mentioned barriers will also largely depend on the type of biofuel and the specific framework conditions. In the following years significant technological promotional and political challenges are thus to be faced in order to establish biofuel as a main pillar of a sustainable worldwide transportation system (Rutz and Janssen, 2008).

17 REVIEW OF BEST PRACTICE GUIDELINES: JATROPHA PROJECTS

Key guidelines for Jatropha projects for ensuring sustainability:

1. Setting minimum standards

Early start up Jatropha projects did not take into account the ecological and sociological complexities involved in large ventures. At present there are several large scale investments in Jatropha based biofuel plants. Since Jatropha grows mostly in developing economies, ensuring the rights of landowners becomes a key component.

It is important to decide on minimum standards for large scale investments in Jatropha that are shared and agreed upon by all stakeholders. These minimum standards are expected to protect local population and their environment.

2. Developing local value chains

A large variety of technologies makes use of Jatropha oil such as local diesel electricity generators that run on Jatropha oil, Jatropha stoves and lamps. However, systematic approaches to link these technologies to Jatropha production have been negligible. Linking the production of these goods to the local production of Jatropha allows generation of regional value chains that expand employment opportunities.

3. Community based initiatives

Social enterprises require some initial support during start-up, but become financially sustainable after this phase. Social enterprises at the community level offer income opportunities for those in desperate need. This income is spent locally creating positive feed-backs for the local economy.

It is important to make existing decentralized Jatropha activities and grassroots enterprises fit for the market to allow their up-scaling.

4. Leveraging Jatropha Carbon Finance

It is important to identify conditions whereby afforestation and fossil fuel substitution with Jatropha oil may be included in carbon finance schemes. It is also essential to develop Jatropha projects by identifying carbon co-financing opportunities.

5. Agronomy research on Jatropha (and its by-products)

In comparison to other cash crops, Jatropha has a huge untapped potential. Potential for Jatropha cake as organic fertilizer, as pellet to burn, as fodder for animals is equally high. It is critical to increase the profitability of Jatropha projects through improved, high-yielding Jatropha crops and through the sales of by-products based on Jatropha press Cake.

6. Regulatory framework and Jatropha ventures

The regulatory framework in different parts of the world (taxation, subsidies, quality standards) determine the profitability of specific Jatropha uses. These frameworks will determine whether it is more profitable to export Jatropha or to sell it on the home market or whether to refine Jatropha oil into biodiesel or whether it is more profitable to use the oil to run diesel engines for off-grid energy services.

It is essential to understand how national policies impact on the profitability of Jatropha investments. Based on this understanding, it is imperative to derive recommendations regarding best policy practices for specific Jatropha related development objectives.

Currently, countries adopt a large variety of policies that provide a sound basis for future policy development.

Developing sustainability criteria for Jatropha

There are key factors to be evaluated in any Jatropha project. These are:

- Integrating socio economic perspectives into large projects
- Creating local value chains
- Finance services for community initiatives
- Leveraging carbon finance potential
- Application and agronomy research on Jatropha

Despite the potential qualities of Jatropha as a sustainable feed stock for biofuel there are specific issues pertaining to translating it into commercial and social benefits. Jatropha projects are very location specific and it has been noted that experiences are not transferable across borders.

Critical sustainability components for Jatropha

Three key issues determine the sustainability of such projects are:

- Adopting best practices in production systems
- Planting, harvesting and processing
- Socially and environmentally sound protocols
- Policies synergising with the needs of local area
- Carrying capacity of the land
- Optimising Jatropha value chain processes
- Yields, conversion efficiencies, value added products

18 STRATEGIC RECOMMENDATIONS

Sustainability of biofuel feedstock production is not a given, and critical focus on the following factors form key criteria and need to be addressed.

- Land use patterns
- Water usage
- Soil impacts
- GHG balance
- Biodiversity loss
- Social dimensions

Land use patterns: a neglected domain

Land resource management and usage pattern is, perhaps, the most critical parameter in Jatropha production in developing economies. Though Jatropha is reported to grow on marginal lands it is noted that it does need good quality land to give the level of yields which can make the project viable in the long term. Experiences in India, South East Asia and Africa have been varied leading to much debate on its viability.

Increasing pressure from commerce to optimise yield per hectare have also tended to force food production off the best land to make way for Jatropha. Land for Jatropha cultivation needs to be evaluated against food or other productive uses of land.

Water usage: the critical component

Claims that Jatropha can grow well in low rainfall regions are being increasingly questioned as experiences have shown that for optimum yields Jatropha does need a higher level of water usage.

It is more likely that commercial pressures to higher yields will drive the use of large scale irrigation which will enable multiple harvests. Near and long term impacts of depletion of ground water resources need to be evaluated for all mega Jatropha projects many of them being planned in ecologically fragile zones. Rising level of shortage of water and projections for further reduction will prove to be a major limiting factor in Jatropha production.

Soil quality

Reports of Jatropha enabling quality improvement of the soil and acting as a binding agent have to be substantiated in different Jatropha growing regions. In mega ventures needing large scale clearances the impact on soil quality can be long term.

GHG balance

In terms of best GHG balance, the choice of the crop and the technology pathways play a key role. Net balance of carbon dioxide savings depends on the amount of energy used for cultivating, harvesting, transporting and converting the plants. It is also noted that production of Jatropha pressed into Straight Vegetable Oil allows for maximum carbon dioxide savings as compared to conversion into biodiesel which involves large chemical inputs. It is essential to carry out a detailed LCA of all the pathways at planning stage itself to ensure sustainability.

Biodiversity loss

Decrease in biodiversity is a natural fall out of biofuel crop production as is exemplified by experiences with Palm oil and Soy, where large forested areas have been cleared for energy crops. Besides, large energy crop farms resort to monoculture cropping thus replacing valuable biodiversity. Resolutions to these issues are being sought through crop mixing, rotation schemes, and scaling down the magnitude of cultivation.

Social dimensions

Perhaps, the most significant factor in ensuring sustainability lies in developing a correct model of socio economic systems related to rural employment and economy. Options to funnel fuel revenues back into the community, inequities in land tenure and poorly implemented resettlement plans pose further challenges for sustainable Jatropha production.

Yet another aspect determining sustainability is to ensure the rights of indigenous people facing displacement from their habitats. It is imperative to set in place properly designed value sharing models in the initial stage itself. Emergence of 2nd generation biofuels will impact the 1st generation fuel feed stocks and long term viability of Jatropha based projects will also need to be evaluated from a socio economic angle.

Developing sustainable economic models

Jatropha cultivation as is practised the world over comprises a variety of business models ranging from large scale with involvement of smallholders, smaller and small-scale production to mega ventures by big corporations. Optimising economies of scale will alter the environmental impacts. In the case of Jatropha, yields will be higher on good quality soil and with sufficient watering than on marginal arid lands and low water usage.

As discussed earlier economic viability will demand better quality land and higher water usage when based on traditional cost benefit analysis. Once other benefits are integrated there is more likelihood of small scale projects on marginal lands being more economical. Apparently traditional approach of cost benefit analysis needs a reassessment to evolve a comprehensive tool for determining project profitability and sustainability.

Environmental benefits need to be considered in this new means of evaluation, including increased productivity from intercropping and the creation of a better more humid microclimate, reduced soil erosion, protection against desertification, and availability of press cake which is also a good quality organic fertiliser.

Way forward

Jatropha oil and Jatropha biodiesel can bring many benefits for developing countries by providing access to clean energy services. In this context, many developing countries are attempting to maximize their biofuel potential.

To ensure sustained use of natural resources, the development of biofuel needs to be carefully planned and managed. Issues such as agricultural land competition, scarce water resources, soil erosion, biodiversity concerns, food versus fuel competition issues, equity concerns of large versus small-scale biofuel development, and biofuel trade issues need closer attention.

Coherent and responsible policies and legislation, capacity building, technology transfer and technological development are needed to ensure that a part of developing countries` growing energy needs can be met through sustainable production of Jatropha biofuels.
Biofuel projects, which are driven by local ownership, in which small farmers produce fuel for their own use or for community use, appear likely to produce and sustained benefits for a rural community.

However, these would need new policy initiatives and policy corrections to fructify.
Some key issues which have to be resolved are as follows:

- Blending requirements, tax incentives, R&D support for biofuel-compatible infrastructure and technologies.
- The economics of bioenergy production are site- and situation-specific, and each country and even location will need appropriate policies.
- Take into account the lifecycle benefits and costs of biofuel production as well as the global production potential, particularly in developing countries.
- Integration with agricultural, land use and energy planning policies.
- Development of International set of standards to facilitate international trade.
- Establishing a biomass trade market can benefit both importing and exporting countries.
- Participation of stakeholders is key to sustainable development and should be taken into account in policy formulation and development of policy instruments.
- Sustainability standards have to be developed tailored to Jatropha, based on general sustainability principles for bioenergy.
- Different business models -small scale and large scale production.
- Ensuring participation of small farmers into large scale production through participatory concepts.
- Involvement of the local population to reduce social or environmental risks related to feedstock production.

PART C: SMALL-SCALE BIOMASS GASIFICATION: EXPERIENCE FROM INDIA AND OTHER ASIAN COUNTRIES AND THE TRANSFER OF TECHNOLOGY TO AFRICA

19 ASIAN BIOMASS GASIFICATION REVIEW

19.1 HISTORY OF GASIFICATION IN ASIA

During World War II, small gasifiers were used for powering vehicles in some Asian countries, e.g. China, India and Japan. The number of producer gas vehicles in 1942 in India and Japan was estimated at 10,000 and 100,000 respectively (NRC, 1983).

Interest in gasifiers disappeared in most countries after the World War II as cheap oil became widely available. However, one country in Asia, China, continued to develop gasifiers for power generation and shaft power applications. Many small rice husk gasifiers of different designs and sizes (25-50 HP) were installed in China in 1950s in rice mills to provide shaft power needed by these mills. In 1960s, a large rice husk gasifier of capacity 160 kWe (Model 6250 M1) was developed to provide electric power to large rice mills. A similar larger gasifier of capacity 200 kWe was later developed for mills with larger power need. Figure 19 shows a schematic of the gasifier of the Model 6250 M1 power unit. The main components of the gasifier are an inner chamber over a rotating grate, a water-jacketed outer chamber and a water seal-cum ash-settling tank. Gasification takes place inside the inner chamber. The char removed by the grate from inside the gasifier settles at the bottom of the water tank, from which it is removed by means of a rotating screw device. The design of the gasifier has some innovative features. Thus, the reactor column does not have any throat or constriction so that low density fuels like rice husk can be gasified without fuel bridging; also, fuel is fed through the open top of the gasifier, which also serves as the inlet for the downdraft air.

The energy crisis of 1973 triggered a great deal of interest in gasifiers in several countries, e.g., India, Indonesia, Philippines, Sri Lanka, Thailand, etc.

In Thailand, producer gas application for different purposes was demonstrated, e.g., electricity production, pumping of water for irrigation, drying of agricultural products and, process heat in small-scale agro-industries. The Department of Public Works installed 143 charcoal gasifier operated generator sets in remote areas (Kjellstrom, 1990). Charung Engineering Company Ltd, a private company, manufactured and started selling gasifiers to generate electricity in 1984 in Thailand. By 1987, twenty-three open-core rice husk gasifier units were installed by this company in Thailand.

In the Philippines, a significant gasifier programme was launched in early 1980s. A number of vehicles were fitted with gasifiers to investigate the feasibility of operation and prototypes of gasifier powered fishing boats, irrigation pumps, and electricity generators were built (NRC, 1983). A government-owned company (GEMCOR) was set up for mass production of gasifiers. About one thousand gasifiers were manufactured under the gasifier programme; these went mainly to agricultural cooperatives (Stassen, 1995).

A significant program on biomass gasification was in place in Indonesia by early 1980s. A total of 49 gasifiers were identified by a survey carried out in 1989 by Biomass

Gasification Monitoring Program (BGMP) sponsored by ESMAP (Stassen, 1995); these consisted of 16 research/pilot reactors, 24 power gasifiers and 9 industrial thermal gasifiers. While all the power gasifiers were demonstration projects, the thermal gasifiers were all purely commercial; the survey found that only 11 of the 24 power gasifiers and 7 of the 9 thermal gasifiers were actually operational.

Development of small-scale biomass gasifiers in India started in a small number of institutes in early 1980s; the main focus of these activities was development of small gasifier engine systems for pumping irrigation water. Department of Non-conventional Energy Sources (DNES), which was established in 1982, launched India's Biomass Gasifier Programme in 1987; the programme was supported by high subsidies and focused on development and demonstration of gasifiers for pumping water as well as power generation.

The oil price crash of 1986 dealt a severe blow to gasifier programmes in most Asian countries, except China and India, where programmes continued through 1990s with emphasis on technology improvement. Development of gasifier stoves for addressing smokiness in case of conventional biomass fired stoves started in China about 1990.

19.2 BIOMASS GASIFICATION IN INDIA

Development of Biomass Gasifiers

Although a large number of gasifier systems were installed under the Biomass Gasifier Programme, most of these soon stopped operation because of a variety of problems, including technical.

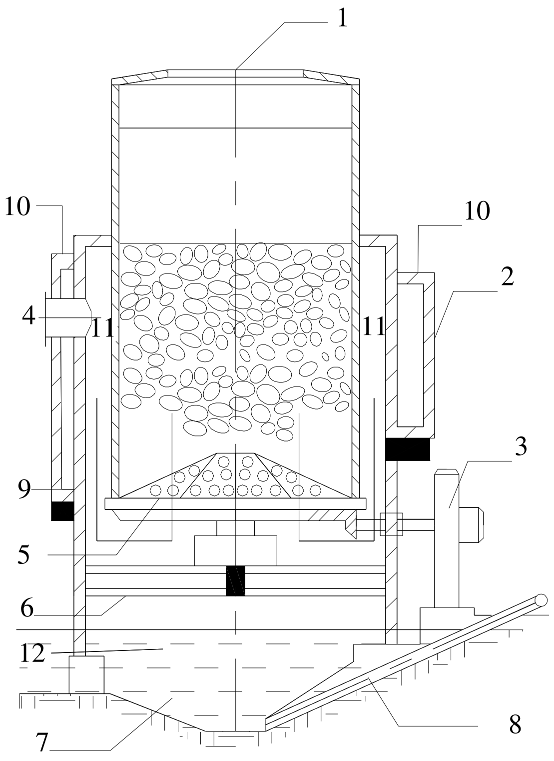
Corrective measures for overcoming the shortcomings of the Gasifier Programme were initiated in early 1990s; these included requirement for certification of gasifier systems by a R&D institution, and reduction in subsidy levels. Promotion of thermal applications of gasifiers was also initiated. Four Action Research Centers (ARCs) were established by the Ministry of Non-conventional Energy Sources (MNES), the successor to the DNES, to facilitate sound development of biomass gasification in India; these Centers played a key role in the development of biomass gasifiers, including providing facilities for gasifier testing.

Current Status of Biomass Gasifiers in India

Power Gasifiers

For electricity generation, biomass gasifiers are normally used to run dual-fuel diesel engines, with about 75% diesel replacement by producer gas; 100% producer gas engines have become available in recent years.

As a result of two decades of support of the Ministry of new and Renewable Energy (MNRE) for development and deployment, biomass gasifiers of capacity up to 500 kW are commercially available in the country today. Table 15 shows a list of Indian gasifier manufacturers.



1. Fuel and air inlet
2. Cooling water jacket
3. Gear box
4. Gas outlet
5. Rotary grate
6. Grate support
7. Ash settling pond
8. Ash removing tube
9. Cooling water inlet
10. Cooling water outlet
11. Gas
12. Ash

Figure 19: Chinese rice husk gasifier

So far, wood is the most common biomass fuel used in gasifiers; use of rice husk for power generation in rice mills is also quite well established. The total installed capacity of biomass gasification-based power generation in the country was 86 MW by the end of March 2008. The Indian Government provides significant subsidies to promote gasifiers for power generation; such subsides include: INR[11]1.50 lakh (INR 0.15 million) / 100 kWe for electrical application with duel fuel diesel engines and water pumping; and INR.15.00 lakh (INR 1.5 million)/ 100 kWe village level electrical application with 100% producer gas engines.

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[11] 1 US$ = 48 INR

Table 15: List of Gasifier manufacturers in India

1.	M/s. Ankur Scientific Energy Technologies Pvt. Ltd., Near Old Sama Jakat Naka, Vadodara-390 008 Tel.: +91-265-2793098, Fax : +91-265-2794042 E-mail: ascent@ankurscientific.com / info@ankurscientific.com Web: www.ankurscientific.com
2.	M/s. Cosmo Powertech Pvt. Ltd. Devpuri, Near Jain Public School, Dhamtari Road, Raipur-492015. Tel : 0771-5011262, Fax : 0771- 5010190 E-mail: cosmo_powertech@yahoo.co.in
3.	M/s. Grain Processing Industries (I) Pvt. Ltd. 29, Strand Road, Calcutta-700001. Tel.: (033) 2431639/2101252, Fax : 91-33-2204508/2103368
4.	Dept of Aerospace Engineering Indian Institute of Science, Bangalore-560 012 Tel: +91-80-23600536, 22932338, Fax: +91-80-23601692 Email: paul@cgpl.iisc.ernet.in
5.	Netpro Renewable Energy (India) Ltd. 139/B, 10th Main, Rajamahal Vilas Extension, Bangalore-560080. Tel.: (080) 3613585, 3613457 / Fax (080) 3611584 E-mail: netpro1@vsnl.com
6.	M/s. Chanderpur Works, Yamuna Nagar – 135 001, Haryana Tel.: 01732-250546, 250964, 251866, Fax : 01732-279852 E-mail : sudhiryn@sancharnet.in
7.	M/s Infinite Energy Private Limited 149-A, Baba House, 1st Floor, Kilokari, Opp. Maharani Bagh, New Delhi- 110014 (M)+91-9212084933 Tel +91-11-65273819 / 65191937, Fax- +91-11-26903696 E-mail ifnfinitenergy@vsnl.net Web: www.infiniteenergyindia.com
8.	Rishipooja Energy & Engineering Company M.G. College Road Gorakhpur – 273 001 (U.P.) Ph: 0551-340 612, 339475
9.	Southern Carbons (P) Ltd. VI/590 B, Development Area, Edayar, Binanipuram P.O. Aluva, Cochin 683502, Kerala Ph: 0484-2540158 / 2532685 / 2543739 e-mail : southerncarb@gmail.com Web- www.southerncarbons.org
10.	Radhe Renewable Energy Development Associate D-110 Rajdoot Industrial Estate 4, Umakant Pandit Udyognagar, Near Mavdi Plot, Rajkot – 360 004 (Gujarat) Ph: 91-981 372567 (O) 571932; Fax: 91-281 372557 Email: radheengineering@radhegroup.com
11.	M/s Agro-power Gasification Plant Pvt. Ltd. B37/181, B1, Birdopur, Varanasi-221010 (UP). 9415221537 (M) 0542-2364285
12.	M/s Ganesh Engineering Works, Poddar House, Jyoti Chowk, Buxer –802101 Bihar. Tel 06183-224571 (M) 9431420171, Fax-06183-227503

All major manufacturers supply both power and thermal gasifiers. Although, the total installed capacity of thermal gasifiers in the country is not well documented, the technology is well established in the country; thus, of the 110 gasifier systems supplied by one manufacturer (Ankur Scientific Energy Technologies Pvt. Ltd) in 2004, 38 were for thermal applications.

Some of the Indian manufacturers have been exporting gasifiers in recent years. Thus, one manufacturer, Ankur Scientific Energy Technologies Pvt. Ltd., claims to have exported 15 gasifier systems in both 2004 and 2005.

Table 16 shows the indicative capital cost of gasifier systems for power applications as reported by Ghosh et al. (2004). Their estimated cost of captive power generation in case of a 100 kW gasifier system was US Cents 8.79/kWh for dual fuel operation and 7.69 for 100 percent producer gas use, compared with US Cent 15.35/kWh for pure diesel operation and US Cent 7.29 for grid electricity. For gasifier operation in remote areas, the cost is significantly higher in applications for which the load factor is low.

Thermal Gasifiers

Although gasifier use for power applications has attracted most attention in India so far, their use for thermal applications appears to be much more attractive. Table 17 shows the summary results for the economics of thermal applications of gasifiers as reported by Ghosh et al. (2004); estimated payback period for replacing liquid fuel or traditional biomass fired systems by gasifier systems for these applications is 6 months and 2 years respectively.

In India, The Energy and Resources Institute (TERI) of India has developed a gasifier stove for commercial applications, e.g. silk reeling and cardamom drying; TERI gasifier stove has also been demonstrated for tobacco curing application in Myanmar.

British Petroleum has introduced a pellet fired gasifier cooking stove relatively recently.

A few other gasifier stove designs are currently in different stages of development and commercialization; these include Sampada Gasifier Stove and Philips Woodstove.

Technology Maturity

With India having the largest small gasifier programme in the world and Indian manufacturers exporting biomass gasifiers to a number of countries, the small gasifier technology is, no doubt well established in India. However, there in no satisfactory testing and certification system for gasifiers in India until now and there is no independent assessment of gasifiers operating in the field to establish the nature of the problems faced in running gasifiers and the percentage of the installed units actually operating. Some studies suggest that gasification technology in India has still certain shortcomings that need to be overcome for facilitating large-scale deployment.

Table 16: Estimated capital costs of diesel engine and gasifier for power generation

Component	Capital cost (US $/kW)
Small gasifier (10-50 kW)	200
Medium gasifier (50-200 kW)	146
Large gasifier (500 kW)	106
Dual fuel engine	104
Producer gas only engine	417

Source: Ghosh et al. (2004); Note: All figures are in 2001-2002 prices.

Table 17: Economic for thermal applications (Source: Ghosh et al., 2004)

	30 kW gasifier	100 kW Gasifier
Gasifier unit capital cost (US$)	3750	12500
For SME units with existing liquid fuel consumption		
Liquid fuel substitution (litres/h)	9.4	31.3
Net savings ($/hr)	3	9
Payback period (months)	6	6
For SME units with existing solid biomass burning		
Biomass saving (kg/h)	30	100
Net savings ($/hr)	0.8	2.7
Payback period (years)	2	2

Technical problems of power gasifiers are mostly because of tar in the gas. The tar remaining in the gas after scrubbing and cleaning tends to condense in the engine manifold and inlet valves and necessitates regular cleaning of the system for reliable operation. That is the reason why gasifiers normally need to be attended to and maintained by skilled labour for smooth and satisfactory operation.

The gas cleaning system is based on water scrubbing. The contaminated water produced on cleaning the raw producer gas is often disposed unsatisfactorily (Gantenbein, 2005).

19.3 HIGHLIGHTS OF BIOMASS GASIFICATION IN THE REST OF ASIA

Rice husk gasification appears to be well-established in China. It is estimated that 120 to 150 rice husk gasifiers were in operation in China in early 1990s; a third of the gasifiers were in Jiangsu Province. At present there are about 300 gasifier plants with a total installed capacity of 50 MW (Li and Ma, 2009). Besides rice husk gasifiers, several other gasifier models have also been developed in China.

In China, technology for downdraft gasification of agricultural residues has been developed to supply gas for cooking to household users (see Figure 20); the produced gas is first cleaned to remove tar and particles and stored in a gas holder, from where it is distributed to households through a network of pipes. Stalks of corn, sorghum, cotton, soybean etc. and woody wastes can be used as feedstock. The size of these systems varies quite widely to serve 60 to more than 1000 house holds (Huang et al., 2003).

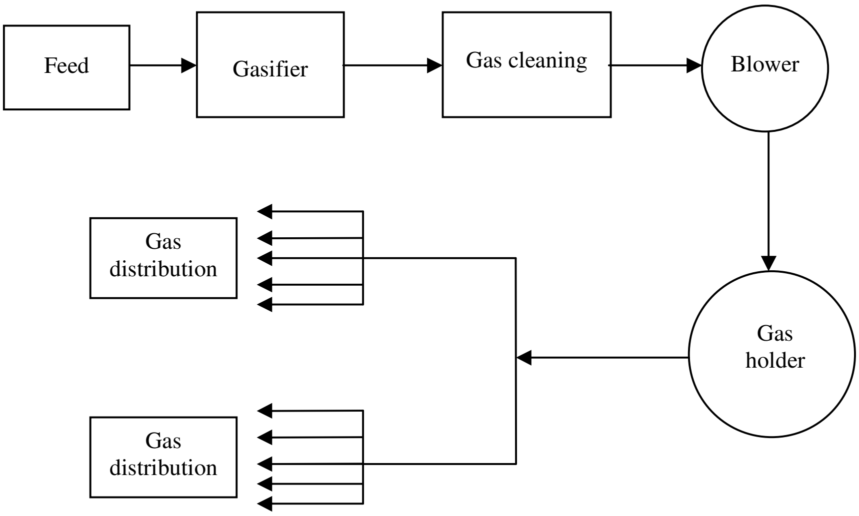

Figure 20: Producer gas supply system for cooking

Table 18: Installed Capacity of Gasification Plants in China

Application	**Number of Units**	**Annual Energy Production**	**Working days/ capacity**
Producer gas supply network	16	24×10^9 kJ	330 days
Cooking	260	7.8×10^9 kJ	300 days
Wood drying	370	560×10^9 kJ	330 days
Electricity generation	150	5.76 GWh	2.4 MW

Source: (Qingyu and Yuan Bin, 1997)

More than 700 gasification plants were reported to be operating in China in mid-1990s; Table 18 presents the number and installed capacity of these gasification plants. More such plants were constructed in the years to come; more than 400 plants were constructed in Shandong Province of China by the year 2005.

The village level gasification plants have been facing a number of problems; most serious among these appear to be the problems created by tar in the gas, which necessitates tedious cleaning of pies and containers on a regular basis. Based on a sample survey, a recent study concluded that more than 50% of the village level gasification plants installed in Shandong province were probably out of operation (Han et al., 2008).

A relatively recent development in China is Circulating Fluidised bed biomass gasifiers (CFBG), which are currently in early stage of commercialization. The first such gasifier was developed by Guangzhou Institute of Energy Resources in a wood products factory; its diameter was 0.41 m and height was 4 m. It used 250 kg/hr of saw dust to produce gas at a thermal efficiency of about 75%. One more circulating fluidized bed gasifier was later installed in another wood processing factory in Hainan province; the electrical capacity of the plant, which can use up to 1500 kg of feedstock per hour, is 1200 kW. A number of CFBG units are currently operating in China, with capacities up to 5.5 MW.

As a result of fall in oil price in the international market and technical problems, particularly those due to tar in the gas, interest in biomass gasification in other Asian countries largely disappeared and most gasifiers installed in 1980s were out of operation by the early 1990s; thus, only 1-5% of gasifiers installed in the Philippines between 1983 and 1986 were found to be in use in 1989/1990 (Stassen, 1995). In Thailand, practically all of the 143 charcoal gasifiers mentioned above went out of operation within a matter of a few years; so were the rice husk gasifiers.

As a result of rising oil price in recent years and growing global concern regarding climate change, interest in biomass gasification has started to grow again; however, no significant gasifier dissemination has taken place yet.

Gasifier stoves, which were originally developed in China, have also been developed in Cambodia, Nepal, Thailand and Sri Lanka.

Figure 20 shows schematic of a natural cross-draft gasifier stove developed at the Asian Institute of Technology, Thailand under a project funded by the Swedish International Development Cooperation Agency (Bhattacharya and Kumar, 2005). Atmospheric air is sucked into the gasifier under natural draft of the stove unit and gasifies the biomass fuel inside the reactor. The produced gas next enters into a gas burner where it burns on coming in contact with secondary air. The fuel for the stove can be sized wood (of indicative size 30 cm x 30 cm x 30 cm), sized twigs or broken biomass briquettes. The fuel is loaded into the fuel chamber of the stove from the top, which is normally kept closed using a lid dipping into a water seal. By loading the fuel as needed, it is possible to run the stove continuously.

The AIT gasifier stove has been disseminated in the region through workshops and training programs; a slightly modified version of this stove has been developed in Nepal. The gasifier stove of Cambodia, called the Vattanak stove, has been developed by a local NGO and is used for palm sugar making.

19.4 FEASIBILITY OF TECHNOLOGY TRANSFER TO AFRICA

Biomass gasification experience in Africa

Africa has only limited exposure to biomass gasification so far. Three Chinese rice husk gasifier-engine systems were installed in large government-owned rice mills in Mali in the mid-1960s. These were probably the first biomass gasifiers to be installed in Africa.

Many developing countries, including Tanzania, initiated biomass gasification programme after the energy crisis of 1973. The BGMP found that most of these gasifers were later abandoned due to technical and operational problems, including 5 gasifiers in Tanzania (Stassen, 1995); however, one of the Chinese gasifiers in Mali, which was also monitored under the survey, was found to be operational as on 1990.

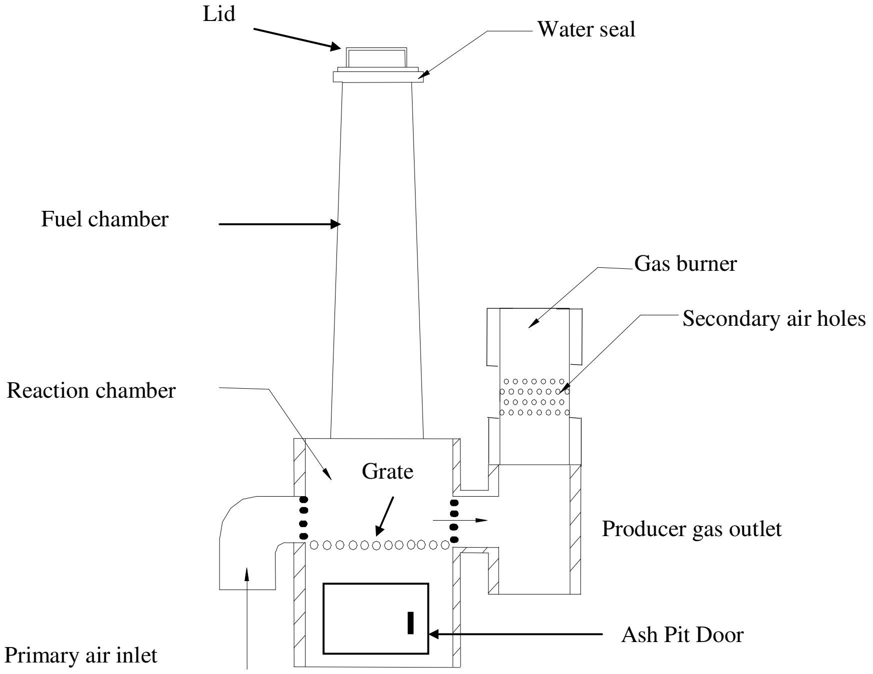

Figure 21: Schematic of natural cross-draft gasifier-gas burner developed at AIT

Interest in biomass gasification started to grow again towards the late 1990s. Based on a survey carried out in Kenya, Senelwa and Sims (1999) concluded that there was significant potential of biomass gasification for small-scale electrification production and cogeneration based on waste wood available in saw mills. They recommended establishment of a demonstration plant for raising awareness about the technology and encouraging private investment.

A dual-fuel 10 kW gasifier system of an Indian manufacturer (Ankur Scientific Energy Technologies Pvt. Ltd) was installed in a farm in Uganda recently. The system has been reported to be attractive compared with a diesel generator with a payback period of about three years (Buchholz *et al.*, 2007). An 80 kW gasifier system from the same manufacturer has been installed in Mozambique.

A high level seminar on biofuels was held in Addis Ababa on 30 July - 1 August 2007. The Addis Ababa declaration contains an Action Plan for Biofuels Development in Africa emphasizing the need for the development of relevant technologies, including biomass gasification (IISD, 2007).

Further interest appears to have been growing in recent years. Thus, a workshop on "Biomass Technology for Sustainable Energy in Western Africa" was organized in Accra, Ghana in 2008; one of the expected outcomes of the workshop was to examine feasibility of biomass gasification.

Eskom, an electricity supply company of South Africa, has initiated a project involving installation of a System Johansson Gas Producer unit in the Melani community in the Nkonkobe region in the E. Cape with assistance from the University of Fort Hare (Mamphweli and Meyer, 2009).

Under a South-South collaboration project funded by the World Bank, the government of Uganda and TERI are running biomass energy pilot activities in Uganda, including successful introduction of gasification technology for thermal and electrical applications through the design and implementation of three demonstration projects (TERI, 2009).[12]

Local Manufacturing

Although there is only limited experience in Africa, one manufacturer in South Africa, Carbo Consult & Engineering (Pty) Ltd, offers low-tar gasifier systems; development work on these systems, called the System Johansson Gas Producers, started in 1980s. A number of installations of these appear to exist currently in different parts of the world including South Africa, Namibia, Netherlands, Japan, and the UK.[13]

Way forward for technology transfer to Africa

Africa has the least electrification rate of the world; the rate was 37.8% in 2005 compared with the electrification rate of 68.3% for all developing countries and 75.6% for the world (IEA 2006); the electrification rate in case of Sub-Saharan Africa was only 25.9%. Initiating large-scale electrification programmes for improving access to electricity in Africa would thus be very important. The continent has high potential of biomass production and Sub-Saharan Africa appears to have the highest potential of all geographic regions of the world (Smeets et al., 2007). Thus, biomass energy could play a major role in electrification of Africa; in this regard, biomass gasification is a very promising technology.

Experience in India suggests that availability of skilled labour for operation and maintenance is a critical factor for success of gasifier projects. This, in turn, suggests that export of one or two gasifiers to be operated in isolation in an African country is unlikely

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[12] http://www.teriin.org/index.php?option=com_ongoing&task=details&sid=21

[13] http://www.carboconsult.com/installations.asp

to be very much successful. Introduction of gasifier technology in significant numbers in any African country would probably require a local manufacturing facility and significant build-up of skilled manpower to ensure proper after-sale service.

Again, experience in India shows that cost of electricity generation using relatively large gasifiers of capacity up to 500 kW is much lower compared with small plants of capacity 10-50 kW. Also, high load factor is important for keeping cost of power generation low. Thus, relatively large installations operating many hours a day, e.g. in SMEs and captive power plants, would be far more attractive than small plants used for only a few hour a day, e.g. in rural electrification projects for lighting only applications. It would also be more feasible to ensure availability of skilled labour in case of large installations. It would be important to take these observations into account in selecting the first few plants to be installed in any African country.

Economics of power gasifier systems can be improved by having a provision of connecting to the grid and selling excess electricity at reasonably attractive rates. This would be particularly important for attracting ESCOs in gasifier based power generation.

As indicated earlier, thermal gasifiers are very attractive in terms of cost-effectiveness, and low maintenance requirement as well as less technical problems associated with tar compared with power gasifiers. As noted by Ghosh et al. (2004), it would be a good idea to initially focus on thermal productive applications.

19.5 CONCLUDING REMARKS

Although a few technical problems remain, biomass gasification is an established technology in India as well as China.

So far the major emphasis of gasifier programme is on power gasifiers; however, thermal gasifiers appear to be more attractive in terms of economics and reliability.

Although there is at least one established manufacturer in Africa, gasifier experience in the continent is still very limited.

Considering the very low level of electrification rate and large biomass potential, a gasifier-based electrification programme appears to be very appropriate and attractive in the case of Africa; feasibility of transfer of gasification technology from India, which hosts the world's largest small gasifier programme, merits detailed assessment.

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