BIODIESEL AND BIOETHANOL PRODUCTION IN RWANDA

1. Project Title

Biodiesel and bioethanol production potential of selected crops in Rwanda

2. Project Team Members:

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3. Introduction

Rising costs of fossil fuels, land degradation, climate change and rural poverty are serious threats to the economic development in many developing countries including Rwanda. Current statistics indicate that oil reserves will be exhausted in less than 60 years.

There is increasing evidence showing a rise in fossil fuel from 625 to 696 Rwandan Francs representing an increase of 11.4 % within very few months of 2007.

To reverse the current situation of rising costs of fossil fuels and environmental degradation in Rwanda there is a need for using low cost and locally available alternative sources of energy. This can be achieved through biodiesel and bioethanol production in Rwanda.

One of the main issues is that of the proposed blending rate which is currently set at E8 and B5 for 2013. To meet 75 percent of the total renewable energy target for 2013 through a 4.5 percent market penetration in biofuels is potentially viable but the weighting of biodiesel to a B2 blend compared to bioethanol E8 will not grow the biodiesel industry. If one looks at the growth in the diesel consumption annually in Rwanda, by 2013 the country will consume approximately 12 million tons of diesel per annum based on a 10-year average. Assuming a two percent blend, approximately 220,000 tons of biodiesel will be required. This is a relatively low target compared to that set by other countries worldwide, e.g. five percent in the UK, and is unlikely to encourage the development of a major biodiesel in Rwanda. Further, the likelihood of the industry being able to procure sufficient local feedstock to satisfy the market is minimal. And the proposal to link the Pricing of biofuels to basic Fuel Price needs to be analyzed.

Finally, there is the issue of food versus non-food crops. The government's stance on this needs confirmation. The statement made is that 'Biofuels supply requires low cost, high yield and surprise agricultural production most of which will not be food crops'. This however is not supported by proposal to utilize palm, sunflower, soya, etc. as the main feedstock for biodiesel production. We have adopted the use of Jatropha curcas as its primary feedstock of choice. Jatropha meet the requirements of being a low-cost, high-yield, non-edible crop which is able to be planted on marginal lands.

The establishment of biofuels industry in Rwanda therefore is not only in the best-interests of the local market but will benefit Africa as a whole. We are positive about the potential of the market and will continue to invest our time, funds and energy towards the creating a viable biofuels market which benefit both the first and second economies.

4. Background

- Rwanda is a rural country with about 90% of the population engaged agriculture (mainly subsistence). It is the most densely populated country in Africa, landlocked with few natural resources and minimal industry. Respiratory illnesses come second after malaria in terms of morbidity in health facilities (p.22, Rwanda PRSP, 2002). Primarily foreign exchange earners are coffee and tea.

- Rwanda has made substantial progress in stabilizing and rehabilitating its economy to pre-1994 levels, although poverty levels are higher now. Gross Domestic Product (GDP) has rebounded and inflation has been curbed. Export earning has been hindered by low coffee and tea prices, depriving the country of much needed hard currency.

Despite Rwanda's fertile ecosystem, food production often does not keep pace with population growth, requiring food imports. Rwanda continues to receive substantial aid money and was approved for the IMF- World Bank Heavily Indebted Poor Country debt relief initiative in late 2000.

An energy shortage and instability in neighboring states may continue to slow growth while the lack of adequate transportation linkages to other countries continues to handicap export growth. Rwanda faces one of the highest human population densities in Africa with most of the population relying on subsistence farming for their livelihoods. As this population increases further, land and resources become scarce and pressure on these resources increases leading to unsustainable use and destruction. Vision 2020 identifies the reduction of the soil productivity and arable land per capita as a main constraint to development of Rwanda (vision 2020, June 2003)

Table 1: An overview of the most important socio-economic indicators

Life expectan birth (years)	**Adult literac rate (% ages and above)**	**Combined gross. Enrolment ratio for primary and second schools**	**GDP per capi (US $)**	**Human develop index**	**Overall ratin a list of 177 countries**
38.9	69.2	53%	1270	0.431	159

Source: UNDP Human Development Report 2004

Rwanda as a country has the same constraints, and opportunities that other countries in the horn of Africa have, but some are unique to Rwanda. One of the main constraint being faced by the population is that of lack of energy, both for power (value adding at village level) and for development. One of the other is the low level of production, of food stuffs, and also of biomass production, these two reasons justify the need for a program that addresses these constraints, so that economic benefits percolate down to the poor, which will go a long way to achieve the 2020 vision program.

- Rwanda's development policy has wisely identified the importance of developing its human resources in the area of sciences and technology, and aside from the immediate benefits of utilizing biofuel technology for energy needs, the development of expertise in this area by Rwandan scientists and engineers will create a marketable knowledge base for the East African region (EAC-East African Community).

- There are three fuels that may have particular immediate applications for Rwanda. In order of their case of production, these are: biodiesel, ethanol and methanol.

5. General information of the project

5. 1. Justifications of the project

Introduction

The method used to produce **Biodiesel** is the **alkaline transesterification** process. In it, two immiscible phases, **triglycerides** and **methanol**, react in the presence of **Na/K hydroxide** during one to two hours in a **batch reactor**, producing **glycerol** and **methyl ester** which can be separated using **gravitational settling**. Then, the upper layer rich in fatty acid methyl ester, FAME'S, is purified using three successive **liquid extractions** with water. The final product is known as **Biodiesel**. The lower phase is mainly glycerol. Methanol is recovered and the catalyst converted into sodium/potassium phosphate, a fertilizer, by adding phosphoric acid. It seems that the reaction can only occur in the interfacial region between the liquids and thus is a very slow process. A vigorous mixing is required to increase the contact area between the two immiscible phases, and this produces an emulsion.

The Diester – the contractor of Diesel and Ester- is the name given to biofuel resulting from vegetable oils. It was launched in 1992 on the initiative of oilseeds producer which has been in session of the field of oil and vegetable proteins. It is just a methyl ester of vegetable oils (MEVO) obtained from the following equation:

1 ton of vegetable oil + 0, 1 T of methanol = 1 ton of Diester + 0, 1 ton of glycerin

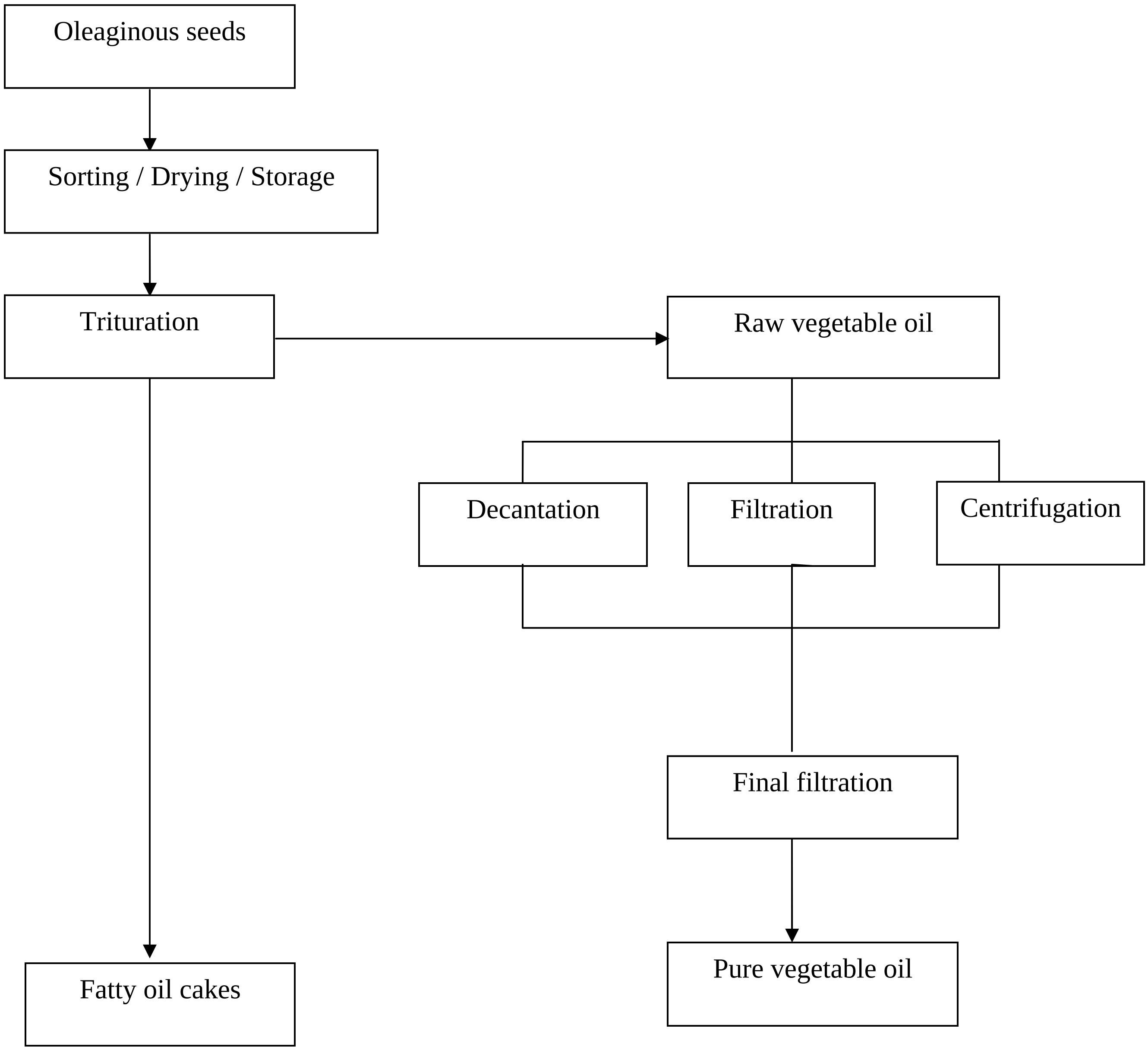
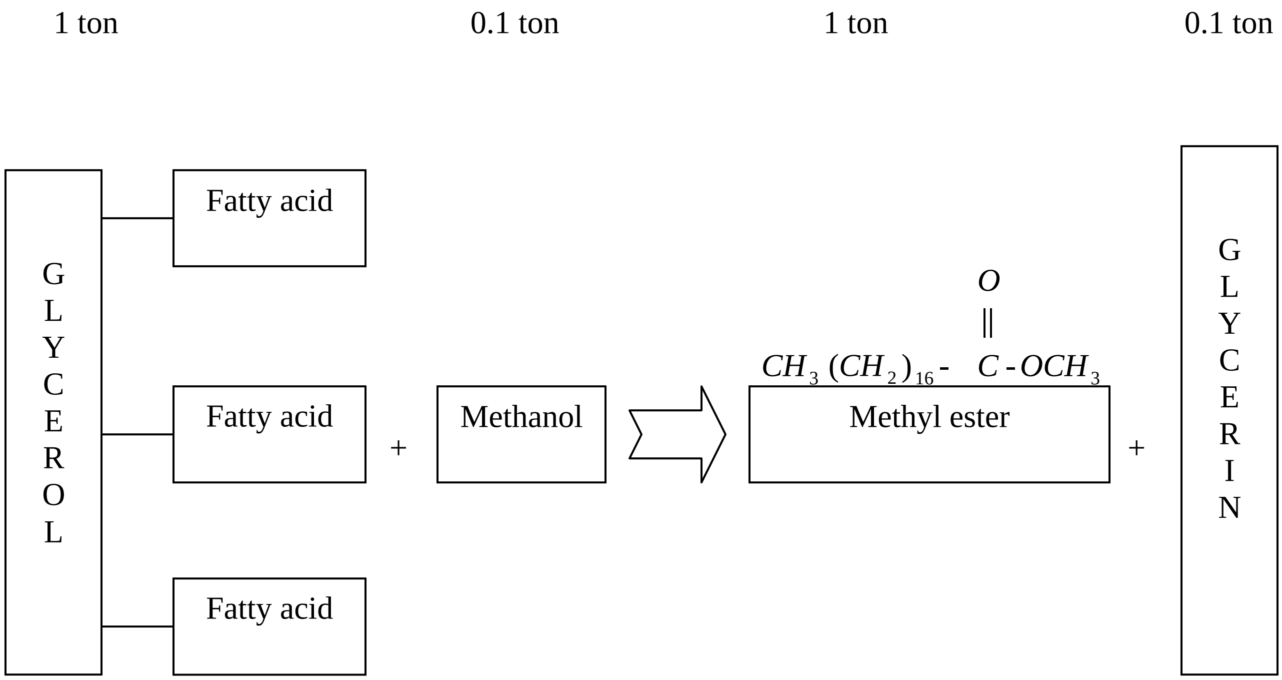


Figure1: Process of manufacture of the PVO

Transesterification



Triglyceride

Figure2: Synthesis of the MEVO

Biodiesel may be manufactured in batch or continuous systems by transesterification, also called alcoholysis or interesterification. In transesterification, one ester is converted to another. The reaction is catalyzed by either acid or base and involves a reaction with an alcohol. As typically practiced, a basic catalyst, such as sodium or potassium hydroxide, is used to convert the glycerol based triesters (or triacylglycerides) which make up fats and oils to methanol based monoesters (or methylesters), yielding free glycerol as a byproduct.

A catalyst is usually used to improve the reaction rate and yield. Because the reaction is reversible, excess alcohol is used to shift the equilibrium to the products side. Alcohols are primary and secondary monohydric aliphatic alcohols having 1-8 carbon atoms. Among the alcohols that can be used in the transesterification process are methanol, ethanol, propanol, butanol, and amyl alcohol. Methanol and ethanol are used most frequently, especially methanol because of its low price and its physical and chemical advantages – polar and shortest chain alcohol (Fangrui and Hamma, 1999)

Branched-chain alcohols, such as isopropanol and 2-butyl have been used in transesterifications of oils and fats in order to reduce the crystallization temperature of biodiesel (Lee, et al., 1995).

Alkaline transesterification is strongly influenced by free fatty acids (FFA), and water content in the raw material. FFA and water content should be kept below 0,5% and 0,06%, respectively to minimize side reactions.

$$\begin{array}{lcl} CH_2-OOC-R' & & CH_2\,OH \\ / & & / \\ CH\ -OOC-R'+3ROH & \rightleftharpoons & CHOH+3R'-COO-R \\ / & & / \\ CH_2-OOC-R' & & CH_2\,OH \end{array}$$

Figure 3: Transesterification of triglycerides with alcohol to produce glycerol and alkyl esters (Biodiesel)

At slightly above room temperature this reaction proceeds conversion of 90-97 %, in a excess of methanol, within approximately 1 hr. The remaining 3-10% is glycerol, mono/di/triglycerides, and free fatty acids. Much of the free fatty acid is converted to soap (sodium or potassium salt of the fatty acid) and water.

Up to 0,5 wt% catalyst is required to promote the transesterification. In most processing flow sheets the catalyst is not recovered and recycled. Thus, fresh catalyst must be continuously added. Washing to remove the spent catalyst is often accomplished with water yielding a significant amount of wastewater from the process. The byproduct glycerol is nearly insoluble in biodiesel and in the feel stock oil and thus forms a separate liquid phase. The biodiesel may require distillation to remove traces of glycerides. The glycerol may be purified by vacuum distillation.

Uses of Alkyl esters

Used as biofuel, the Diester is blended into the gasoil at the ratio of 30% which is its environmental optimum, in order to be used in their fleets of vehicle (truck, heavy lorries, commercial and light vehicles …)
Even though it is first of all known as biofuel, the Diester is a renewable energy. More over, it is biodegradable and non-poisonous. The Diester makes it possible to decrease the rejection of many pollutants e.g. the black smoke and unburnt hydrocarbons. Being sulfur free, it also increases the working of catalytic

converters. Given that it has the renewable properties, it reduces the emission of greenhouse gas.

The diester characteristics could be compared to those of gasoil and it is mixes with gasoil in all proportions and is used without any modification of the vehicle performed.

The development of the Diester is the integral part of the strategy of Protocol of Kyoto in favour of reduction of greenhouse gases. This is true as it is offering the solution adapted to the sector of transport, which contribute considerably to the increase of greenhouse effects (+22% since 1990, the reference date of Kyoto agreements.) This is confirmed by the proposal of the directive of PTK encouraging the use of biofuel.

When producing Diester, the vegetable proteins are also produced. Actually, the remaining part of the grain after oil extraction used in diester, called oil cake", is rich in vegetable proteins used in feeding of animals. Also the diester production generate the vegetable glycerin highly used in pharmacy and cosmetic products, like toothpaste, care creams or shaving foams…

The diester has also found to have cleaning agent application specially during the catastrophe of Erika. It has the properties of softening and making soluble the tars and heavy fuels. Thus, the diester can be poured in rocks so that hydrocarbons they contain can be soluble. It take time to penetrate into thick layer and this time is depending on its exposure to sunlight and on its thickness.

How biodiesel works

Biodiesel runs in any unmodified diesel engine. There is no "engine conversion" typical of other alternative fuels. The diesel engine can run on biodiesel because it operates on the principle of compression ignition whereby air is compressed and the fuel is sprayed into the ultra-hot, ultra-pressured combustion chamber. Unlike gasoline engines, which use a spark to ignite the fuel/air mixture, diesel engines actually use fuel to ignite hot air. This simple process allows the diesel engine to run on thick fuels. Since biodiesel is chemically similar to petroleum diesel fuel, you can pour biodiesel right into the fuel tank of any diesel vehicle. Biodiesel has lower emissions, it is made domestically (which increases national security), it does not affect engine performance and it is produced from plants. Since plants are a product of solar energy, biodiesel is "liquid solar fuel".

Biodiesel benefits

1) Biodiesel runs in any conventional, unmodified diesel engine. Non engine modifications are necessary to use biodiesel and there is no “engine conversion”. In other words, “you just pour it into the fuel tank”.
2) Biodiesel can be stored anywhere that petroleum diesel fuel is stored. All diesel fueling infrastructure including pumps, tanks and transport trucks can use biodiesel without modifications.
3) Biodiesel reduces carbon dioxide emissions, the primary cause of the Greenhouse Effect, by up to 100 %. Since biodiesel comes from plants and plants breathe carbon dioxide, there is no net gain in carbon dioxide from using biodiesel.
4) Biodiesel can be used alone or mixed in any amount with petroleum diesel fuel. A 20 % blend of biodiesel with diesel fuel is called “B20”, a 5 % blend is called “B5” and so on.
5) Biodiesel is more lubricating than diesel fuel, it increases the engine life and it can be used to replace sulfur, a lubricating agent that, when burned, produces sulfur dioxide – the primary component in acid rain. Instead of sulfur, all diesel fuel sold in France contains 5 % biodiesel.
6) Biodiesel is safe to handle because it is biodegradable and non-toxic. According to the Biodiesel Board, “neat biodiesel is as biodegradable as sugar and less toxic than salt”.
7) Biodiesel is safe to transport. Biodiesel has a high flash point, or ignition temperature, of about 300 deg. F compared to petroleum diesel fuel, which has a flash point of 125 deg. F.
8) Engines run on biodiesel normally and have similar fuel mileage to engines running on diesel fuel. Autoignition, fuel consumption, power output, and engine torque are relatively unaffected by biodiesel.
9) Biodiesel has a pleasant aroma similar to popcorn popping in comparison to the all-too-familiar stench of petroleum diesel fuel.

5. 2. Lessons learnt from successful case studies.

5. 2. 1. Biofuel could place Africa «at the forefront of a new wave of innovation» - Biofuels set to expand mobile coverage

THE GSM ASSOCIATION, Ericsson and multinational telecommunications group MTN have teamed up to establish biofuels as an alternative source of power for wireless networks in the developing world. The three organizations have set up a pioneering project in Nigeria to demonstrate the potential of biofuels to replace diesel as a source of power for mobile base stations located beyond the reach of the electricity grid.

Biodiesel has several important advantages over conventional diesel as a power source for base stations. Biodiesel can be produced locally, creating employment in rural areas, while reducing the need for transportation, related logistics and security. Biodiesel has a much lower impact on the environment than conventional diesel. The cleaner burning fuel results in fewer site visits and also extends the life of the base station generator, reducing operators' costs.

Affordable and accessible mobile communications

«The early adoption of biofuel-powered mobile networks would place Africa at the forefront of a new wave of innovation that is making mobile communications affordable and accessible across the developing world », said Karel Pienaar, CTIO of the MTN Group.

In a pilot project, supported by expertise and funding from the GSMA's Development Fund, Ericsson and MTN are setting up a pilot biodiesel-powered base station solution in Lagos and will later deploy biodiesel-fueled base stations in rural regions of south eastern and south western Nigeria. The three organizations are setting up a supply chain designed to benefit the local population by sourcing a variety of locally-produced crops and processing them into biofuel. Groundnuts, pumpkin seeds, jatropha, and palm oil will be used in the initial pilot tests.

«The extension of mobile networks into rural areas is vital to boost the social and economic welfare of the developing world; » said Rob Conway, CEO of the GSMA, the global trade association for mobile operators.

«Biofuels have the potential to make that happen by giving mobile operators local access to a commercially and environmentally sustainable power supply. »

The GSMA and Ericsson will draw on the findings of the pilot to help operators across the developing world determine whether they can use biodiesel to power their networks in rural areas.

«In order to reach the next billion mobile users, we need to reach lower-spending segments of the population profitably », said Bert Nordberg, Executive Vice President, Sales and Marketing, Ericsson.

«By using locally-produced biofuels, we could significantly lower the cost of operating mobile base stations in rural areas. »

5. 2. 2. Biofuel production success in India.

Available reports indicate that in 2006, a Catholic Priest named Inacio Almeida who obtained 3 liters of biofuel from 10 kilos of *Jatropha curcas* seeds attracted the attention of the Indian Government and Investors.

The Father Inacio Almeida is also known as «the priest of gasoil» after successfully manufacturing from plants growing in arid regions like Goa State. Planting Jatropha curcas created more jobs and generated revenues in villages. He further indicated that in 2009, the public finances are expected to gain five billions of rupees (equivalent of 85 millions of euros).

Jatropha oil has multiple uses. For example. The oil extracted from jatropha seeds (or jatropha curcas) can be used to replace the candle, to make soap, or even move away the insects and the rats. The oil cakes, can replace coal for cooking. Biofuel from jatropha can be used alone or in blending with the gasoil.

In 2005 tests carried out revealed that a car was driven by Jatropha biofuel for a distance of 500 km (between Maharashtra State and Panaji – Goa Capital).

Many people already find there the opportunity of developing a fuel at lower cost, with economic repercussions and lasting growth, in the current international context of oil prices rise. Hundreds of inhabitants of the old Portuguese enclave already planted seeds of jatropha, a plant imported in the 16th century by the Portuguese who used it as demarcation of pastureland of livestock which hardly appreciated its odor.

Then, in order to make experimentation, an industrialist of Goa Manuel D'Costa planted more than 2000 young growths on mining discharges. He adds "above the revitalization of the space, the plantation of jatropha has the potentiality of being the biofuel that could replace the gasoil". According to the forest person in charge for Goa, the government already planted ten hectares of jatropha.

6. Methodology

The alkali-catalyzed reaction mechanism consists of three steps. The first step is an attack on the carbonyl carbon atom of the triglyceride molecule by the anion, the methoxide ion, to form a tetrahedral intermediate. In the second step this intermediate reacts with the methanol to regenerate the anion. In the last step, rearrangement of the tetrahedral intermediate results in the formation of a fatty acid ester and a diglyceride. When *NaOH*, *KOH*, K_2CO_3 or other similar catalysts were mixed with alcohol, the actual catalyst alkoxide group is formed. A small amount of water generated in the reaction may cause soap formation during transesterification.

The accepted stepwise reactions for the basic transesterirification of palm oil are:

$$TG + CH_3\,OH \rightleftarrows DG + R'CO_2\,CH_3$$

$$DG + CH_3\,OH \rightleftarrows MG + R'CO_2\,CH_3$$

$$MG + CH_3\,OH \rightleftarrows Glycerol + R'CO_2\,CH_3$$

Figure 4: Transesterification of tryglycerides with alcohol to produce glycerol and alkyl esters (Biodiesel)

Palm oil transesterification with methanol using NaOH as catalyst in a batch was studied at 50°C using a methanol/oil mola ration of 5:1 during 2hrs and we followed the progress of the the reaction by the determination of triglyceride, diglyceride, monoglyceride, total methyl esters and glycerol.

6. 1. Project's objectives

The main objective of this project is to assess the biodiesel and bioethanol production potential of different crops that are found in Rwanda. More specifically the objectives will be:

a) To identify suitable sites for various crops (adaptability of different oil crops) found in Rwanda
b) To determine the appropriate sylvicultural management regimes maximizing productivity of Rwandan oil crops.
c) To determine relationships existing between oil crop productivity and biodiesel production.
d) To assess the impact of biodiesel production on socio-economic conditions of Rwandans.

To achieve the project’s objectives therefore, there is an urgent need for establishing strong collaborative linkages between IRST, National and International Institutions/Organizations and Private Sector.

7. Partnership

7. 1. International partners in biodiesel and bioethanol production and areas of collaboration:

7. 1. 1. International Partners:

a) **AGERATEC BIODIESEL SOLUTIONS A B**

Herrebro

60597 Norrköping

SWEDEN

Tél. : 00(46)11335270

Fax. : 00(46)11170555

b) NATIONAL RESEARCH DEVELOPMENT CORPORATION

(NRDC)

Anusandhan Vikas, 20-22,

Zamroodpur Community Centre,

Kailash Colony Extension,

New Delhi – 110048,

INDIA

7. 1. 2. Areas of collaboration:

- Potential production of Biodiesel;
- Knowledge systems and other Biodiesel Production-Programs;

• Analytical Methods for Biodiesel, Fuel Properties (cetane numbers, viscosity, performance, oxidative stability, lubricity, toxicity, glycerol,...), Pollutant Emissions from Diesel Engines;

• Biodiesel Quality Control and Management, Environmental Implications of Biodiesel;

• Exchange programs concerning current scientific methods;

• The sharing of statistical information;

• Development and promotion of Biodiesel Production in both Rwanda, East African Community and in other developing countries;

• Exchange of academic and training programs for researchers, technicians, staff and scientists / experts with the view for capacity development, capacity building, transfer of skills and appropriate technology;

• Exchange of relevant information and cooperation in fields of interest to both institutions;

• Other Biofuels and science research areas that may be of mutual interest and benefit to the Parties;

• Joint publications and conference presentations for collaborative research projects;

• Funding for research based on joint research activity;

• Commercialisation of products emerging from the collaborative research activity;

• Supplying seed decorticators, oil extracting machines, biodiesel and bioethanol processors, chemicals and other research equipment needed to control quality of both raw oil, raw materials and biodiesel / bioethanol in the Rwandan National Laboratory;

• Maintaining the supplied research equipment / processors.

• And other services required or arising in the course of delivery of abovementioned services.

7. 2. National partners:

MINADEF, MINALOC, MININFRA, MINITERE, MINAGRI, RBS, UNR, ISAR, KIST, ISAE, WFP/PAM, Moringa Growers Cooperative, etc.

8. Conclusions

In Rwanda, there are several oil crops with high potential for biodiesel and bioethanol production. The most common oil crops found in Rwanda include palm trees, avocado, jatropha, castor bean and moringa yielding 5950, 2638, 1900, 1413 and ? liters of oil/ha respectively. By comparison, reported oil yields from soybean, which is commonly used to produce biodiesel in temperate climates is only 446 liters/ha.

Palm oil has the highest yield of common agricultural crops, and new varieties have been developed for high altitude (950 m) and low temperature production. These varieties have great potential for cultivation in Rwanda. However, as full production from time of planting requires approximately three years, intermediate crops must be considered. Avocado is widely cultivated in Rwanda, and currently the oil containing seeds are not utilized. This may be an excellent source of oil for biodiesel production and could provide additional income for rural farmers. Another option might be to intercrop new palm oil plantings with a fast growing, high oil yielding plant such as castor bean. This could allow immediate return while oil yield palm plants are maturing. Drought tolerant plants such as Jatropha which can live for 40 years, and provide high value oil, might be suitable for marginal areas. Available *Moringa oleifera* plantations may also play an important role in biodiesel production in Rwanda

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