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# Technologies for Biodiesel Production in Sub-Saharan African Countries

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Additional information is available at the end of the chapter

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## 1. Introduction

The importance and relevance of generating liquid fuels from biomass and producing biodiesel from vegetable oils given the enormous environmental advantages the process offers cannot be overemphasized. The increasing popularity of biodiesel has generated a great demand for successful commercial production methods, which, in turn, calls for the development of technically and economically sound process technologies. The applicability of various technologies employed currently for biodiesel production under diverse catalytic and process systems is explored, with particular attention paid to sustainable protocols for sub-Saharan Africa. Africa holds abundant renewable energy sources with an estimated 1.1 million gigawatts of potential hydropower capacity, geothermal and solar energy as well as substantial biomass potential. Irrespective of this, however, in reality there appears to be a rather limited utilization of these renewable energy sources as modern renewable energy sources account for less than 2% of primary energy demand in sub-Saharan Africa as far back as in the 1990s [1]. Sub-Saharan Africa also has significant amounts of renewable energy that could still be exploited, as renewable energy technologies (RETs) have demonstrated their capacity to meet energy needs where the conventional energy supply options have proved unsuccessful. Modern biomass technologies in Africa need to be developed to their optimum potential as this specifically would offer sub-Saharan Africa self-reliance with respect to energy supplies at the national and local levels with economic, ecological or environmental, social and security benefits [2]. Energy consumption in Africa is largely dominated by combustible renewable resources and if Africa were to take its rightful place in the developing renewable energy market, the advantages would be abundant. A majority of African countries obtain their main household energy resource from biomass used for various activities such as cooking, drying and space heating. According to reports by Energy for Sustainable Development in Africa,

primary energy consumption has been increasing steadily to about 24% [3]. While liquid fuels remain the largest source of energy, fossil fuels are expected to meet much of the global energy required for sustainable development. Predictable high world oil prices in the nearest future, though prices are currently very low, may lead many energy users to shift from liquid fuels when feasible will make a way for renewable energy sources [4]. Among the many possible resources, biodiesel has received the most attention as a promising substitute for conventional petrol-diesel fuel.

## 2. Biofuels

Biofuels are energy sources that are produced from biomass—the living matter of plants or organic waste. Biofuel comprises of liquid or gaseous fuels used basically for the transport sector, which are primarily produced from biomass. They include ethanol, methanol, biodiesel, hydrogen and methane, respectively. Liquid biofuels to fuel vehicles, engines while gaseous fuels cells for electricity generation. An estimated 54 billion litres of biofuels was recorded in 2007 as a result of increased world production and these gains meant biofuels accounted for 1.5% of global supply of liquid fuels, up 0.25 % from the previous year [5]. First generation biofuels include two main types:

- Bioethanol produced from plant sugars of biofuel crops, such as sugarcane and maize, which ferments to produce ethanol. The ethanol produced can be further blended with 5–10% gasoline fuel for use in normal cars; however, higher percentages of ethanol are needed for specially adapted cars [6].
- Biodiesel synthesized from a chemical reaction between triglycerides and an alcohol. The use of triglycerides without any modification directly in modified diesel engines cut biodiesel processing costs and eliminates excessive glycerol by-product from the process.

The transesterification of vegetable oils has been widely known and employed since the 19th century. In fact, the process currently in use for making biofuels from biomass still follows former protocols and the feedstock utilized for their preparation remain very similar. Peanut, hemp and corn oil and animal tallow conventionally used for biodiesel have been partially replaced by soybean; rapeseed, recycled oil while forest wastes, trees and sugarcane are used for bioethanol. According to Luque et al. [7], the history of biofuels is however more political and economic than technological. In the 18th century, Rudolph Diesel firstly demonstrated using peanut oil as diesel for his compression ignition engine at a world exhibition in Paris. These particular vegetable oils were employed as fuels in diesel engine before engine alterations were made, enabling the use of currently known diesel fuel. Biofuels were believed to would offer a solution to fuel issues in the transportation industry not only by Diesel but also by Henry Ford who was convinced that renewable resources were essential to the success of future automobile designs to be run with ethanol. During the World War II, countries engaged in the war utilized biomass fuels in their machines and despite their use during this time, biofuels have remained inconsequential due to the discovery of fossil fuels and a concrete petrol-based industry that made the world very dependent on petroleum. The potential of

biofuels reappeared in public awareness, brought back by various bioenergy programs established in Brazil in 1975 and international organizations such as the International Energy Agency (IEA) Bioenergy, established in 1978 by the organization for Economic Co-operation and Development (OECD), which aimed to expand bioenergy research, development and implementation between countries that have related national programs. The United Nations (UN) International Biofuels Forum is constituted by a number of countries including Brazil, China, India, the United States, and European Union along with South Africa, which is the only country from the African continent. The United States, Brazil, France, Sweden and Germany are world leaders in biofuel development and consumption. The worldwide advancement of the biofuels industry, however, over the recent years has mostly been triggered by a global crisis produced by the increased use of fossil fuels, resulting in limitation of supply, previously high inflationary prices and negative environmental impact. However, towards 2008, interest in biofuels underwent a huge surge largely accredited to the compulsion towards mandatory fuel blends in Europe and other developed nations [8]. Sub-Saharan Africa's biofuel production potential was emphasized by several research studies, which drove the intense interest for African biofuel investments [9–11] and stimulated international investors to acquire large regions of land for feedstock plantations in sub-Saharan Africa [12–14]. The environmental and social sustainability of biofuels has been under extensive scientific scrutiny with initiatives emerging to develop guidelines for sustainable production according to the communiqué of the Roundtable on Sustainable Biofuels [15,16] with regards the market regulations from consumer countries and producer countries (e.g. South Africa and Mozambique) [17]. According to Mwakasonda, Southern Africa possesses largely untapped potential of biofuels in the world [18] with biodiesel development in sub-Saharan Africa still regarded to be in its initial stages. This has initiated deliberations and discussion among policy makers, development practitioners and other stakeholders to foster the development of biofuels in Africa. Bio-fuels are considered as a source of foreign exchange especially for oil-deprived countries via the development and use of locally produced renewable fuel, reduction of demand for imported petroleum, boosting of local agriculture production and additional markets and revenue to farmers, leading consequently to the increase of some rural people's purchasing powers and quality of life, beneficial environmental impact through the use of organic municipal solid waste materials to generate a higher value end-product, reduced level of carbon dioxide emitted by motor engines and subsequent preservation of the atmosphere [19]. It is worthy of mention that despite these benefits, biofuels/biodiesel production in sub-Saharan Africa has met with challenges and caused some unforeseen problems. For example, in several African countries, the biofuel policy priorities at national level revolved around energy security and rural development as well as attempts to take advantage of carbon finance where available. Despite policy and investors interest, several early biofuel ventures collapsed. According to research studies carried, there is evidence to suggest that lack of proper agronomic knowledge, lack of appropriate institutions to regulate nascent biofuel sector, investor caution, lack of market development and a growing understanding of the potential environmental and socio-economic impacts has left poor local communities poor or even poorer [20]. Studies have also shown that poverty outcomes are directly related to the loss of access of local

communities to natural ecosystems implying that there may be significant linkages between the environmental and socioeconomic performance of biofuel projects [21].

## 2.1. Biodiesel

Biodiesel presents the following advantages: improved fuel performance, increased lubricity, higher cetane number and flashpoint as compared to fossil-diesel, lower toxicity to living organisms, reduced exhaust emissions, and its versatility for use as fuel [22–25]. It is a local renewable source of energy that reduces importation of energy and affords improved security of energy supply. It is highly biodegradable [26, 27]. It also improves the quality of the environment with less harmful soot generated from the exhaust of vehicles. Biodiesel when mixed with fossil diesel creates a biodiesel blend suitable for diesel engines with minimal modifications as the superior lubricity of biodiesel increases functional engine efficiency; with a low viscosity and lower carbon monoxide emissions [28], biodiesel is user-friendly, non-toxic, and free of sulfur [29] and aromatics [30]. Possessing a high flash point eases storage and the presence of a higher amount of oxygen in biodiesel fuel guarantees the complete combustion of hydrocarbons. The production of biodiesel (methyl esters) from vegetable oils represents an alternative means of producing liquid fuels from biomass, and one which is growing rapidly in commercial importance and relevance due to the fluctuations in petroleum prices and the environmental advantages the process offers. Biodiesel can be produced from a variety of feedstock, vegetable oils, waste cooking oils and animal fats. These oils typically consist of  $C_{14}$ – $C_{20}$  fatty acid triglycerides. In order to produce a fuel that is suitable for use in diesel engines, these triglycerides are usually converted into the respective mono alkyl esters by base-catalyzed transesterification with short chain alcohol, usually methanol.

## 3. Catalytic processes

Catalysts are mainly classified as homogeneous or heterogeneous groups. Homogeneous catalysts act in the same phase as the reaction mixture, whereas heterogeneous catalysts act in a different phase from the reaction mixture. Heterogeneous catalysts have the advantage of easy separation and reuse due to the advantage of being in a different phase from the reaction medium. Presently, the biodiesel industry is dominated by homogeneous catalytic applications due to the basic convention and less time required for the conversion of oils to their respective methyl esters. NaOH and KOH are mainly used because they are easily soluble in methanol, forming sodium and potassium methoxide respectively while enhancing transesterification reactions to completion. When the acid value (AV) of the oil is high, an acid catalyst such as hydrochloric acid or sulfuric acid is used to lower the AV and then the alkali catalyst is utilized for biodiesel synthesis.

### 3.1. Homogeneous/heterogeneous catalysis

Conventional biodiesel production is done via base-catalysed transesterification using homogeneous alkaline catalysts. This is the most commonly used technique as it is considered

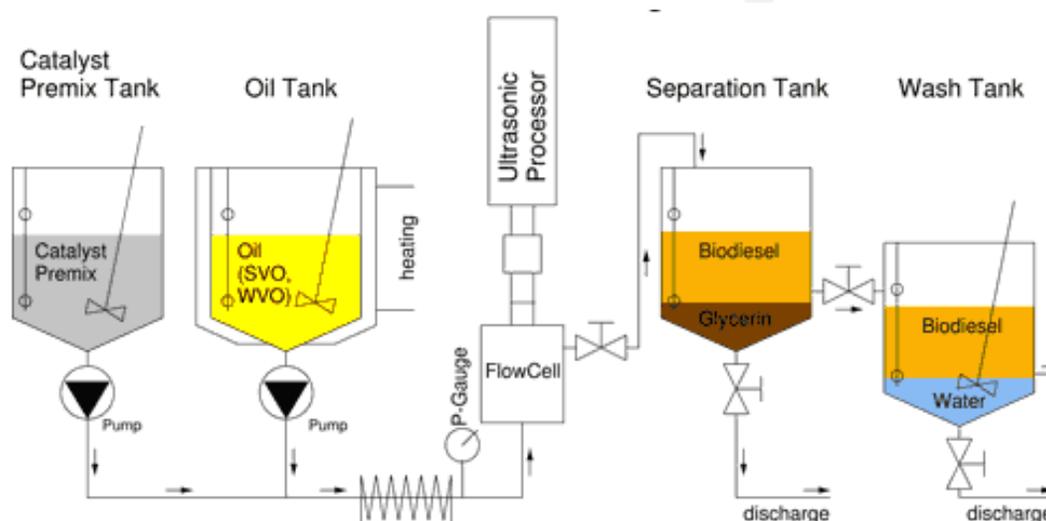
to be the most economical process [31]. The fact that homogeneous catalysts cannot be reused makes conventional heterogeneous catalysis preferable as it offers a series of advantages among which are easy separation of products, reusability of catalysts and reduced amount of waste water during biodiesel production. Heterogeneous catalysis is thus considered to be a green process, as the purification steps of products are much more simplified with high yields of methyl esters being achieved [32]. Economically, heterogeneous catalysis poses a better alternative with regards the reduction of the costs associated with the purification and separation of reaction products in biodiesel production. This development could lead to a cost-effective process that is environmentally friendly. For example, the high catalytic activity of calcium containing natural and biological materials (eggshells, limestone calcite, cuttlebone, dolomite and hydroxyapatite) for transesterification reactions have been reported [33]. Waste coal fly ash-based catalysts and fly ash-based zeolites have also proved to be successful catalysts and offer an alternative route for the utilization of South African fly ash in transesterification reactions for biodiesel production [34, 35].

## 3.2. Process systems

### 3.2.1. *Ultrasound technology in biodiesel production*

Chemical reactions involving ultrasound homogenization/technology has been studied and has developed as an expanding research area in the field of biodiesel production. Utilizing ultrasound technology for producing biodiesel employs ultrasonic field known to produce chemical and physical effects that arise from the collapse of cavitation bubbles. The mixing intensity is considered a very important parameter to enhance a progressive transesterification reaction due to the fact that oil and alcohol are immiscible. Thus low-frequency sonication can be used to create emulsions from immiscible liquids and this effect could be employed for biodiesel preparation. The use of ultrasound technology has thus proven to provide a latent alternative to conventional biodiesel production process via transesterification by initiating substantial mechanical energy required for mixing and activating the transesterification reaction for biodiesel synthesis [36]. One major problem, however, in the transesterification of oils using methanol is the fact that alcohol is a poor solvent for fatty materials. Thus the need for homogenization of the reaction mixture since this reaction can only occur in the interfacial region between the liquids (due to the fact that fats and alcohols are not totally miscible); hence, the application of vigorous mixing is required to increase the area of contact between the two immiscible phases. This method of homogenization has been found successful for both biodiesel production batch processes and continuous operation [37–39]. The use of ultrasound technology in biodiesel production presents an efficient, swift and economically functional process with reduced reaction time, static separation time as well as generally higher yields over the conventional process [38, 40]. The effects of use of mechanical stirring, ultrasound technology and hydrodynamic cavitation on soybean biodiesel yields were studied under the following parameters (catalyst, KOH; feedstock, soybean oil; solvent, methanol; alcohol/oil molar ratio of 6:1, temperature of 45°C) by Lifka et al. [41] and Ji et al. [38]. Results obtained showed that the application of ultrasound technology enabled faster reaction periods and higher yields in comparison to mechanical stirring. Conversely, Thanh et al. [42] report

identical biodiesel yields during alkaline transesterification of vegetable oils via both mechanical stirring and ultrasound processes using KOH. Employing ultrasound processes and solid catalysts in biodiesel synthesis as compared to conventional batch processes has also been found to reduce reaction time drastically. Kumar et al. [43] also report a 98.53% biodiesel yield when a combination of an ultrasound process and a solid catalyst is employed as compared to a conventional batch process. Figure 1 shows a schematic of biodiesel production using ultrasound technology. Production of biodiesel under the ultrasonic processing possess the following advantages, reduction in processing time, less amount of alcohol, minimal catalyst, faster separation time and reduced reaction temperature as revealed in several studies [37–43].



**Figure 1.** Schematic of biodiesel production using an ultrasound (Reproduced with permission from ©Hielscher Ultrasonics)

### 3.2.2. Application of jet mixing in biodiesel production

The application of jet mixing in commercial biodiesel production has been developed and applied to improve mixing and enhance mass transfer between vegetable oils/ animal fats with methanol/ethanol in stirred tank reactors in the presence of basic or acidic catalysts [44]. The challenges related to conventional biodiesel production processes include the limitation of reaction rate by mass transfer between triglycerides and alcohol due to factors of immiscibility; high conversion limitations in the absence of product removal since transesterification itself is a reversible reaction; and disadvantage of batch mode operations of small and medium-scale biodiesel commercial processes (against the advantages of continuous operation) necessary for the development of process intensification technologies. This technology has been applied successfully in South Africa for commercial biodiesel production and has recorded shorter reaction profile, low molar ratio of alcohol to oil as well as lower catalyst concentrations. The operating cost and energy consumptions required to purify biodiesel could be minimized while the recovery of excess alcohol and catalyst by-products during downstream processing made more efficient.



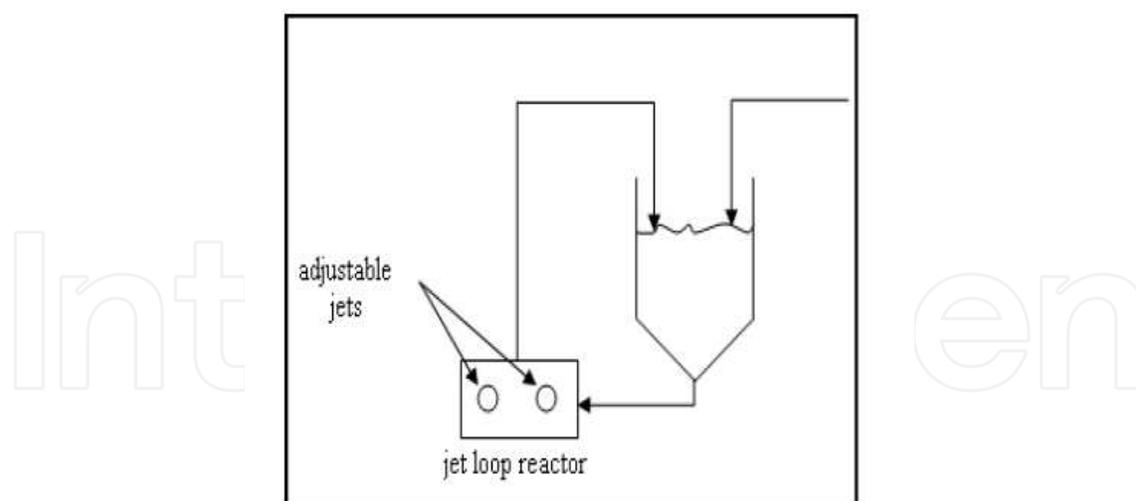
**Figure 2.** Stirred tank reactors using the jet mixing technology

### 3.2.3. *Jet reactor*

A variety of practical engineering applications have employed the use of impinging jets to enhance heat transfer due to the high local heat transfer coefficient it presents. These applications include quenching of metals and glass, cooling of turbine-blades, cooling and drying of paper as well as the cooling of electronic equipment. Extensive review and numerous studies that expound heat transfer enhancement via impinging jets can be found in literature [45-47]. Jet reactors are reactors based on the impinging jet technology. This system provides intense mixing under pressure with different nozzle sizes which were specially developed for steel cutting (with water) and further developed for the mining sector especially in the goldmine sector of South Africa. The application of jet reactors as shown in Figure 2 was further developed in a continuous process reactor mainly for the production of biodiesel in South Africa by Nieuwoudt [48]. The jet-loop system (schematic shown in Figure 3) has been optimized in different studies and upscaled in medium- and large-scale biodiesel commercial plants in southern Africa [48].

### 3.2.4. *Membrane technology*

Biodiesel production using membrane reactors is a new concept that is still being tested for optimal conditions. However, there are numerous prospects to finding paramount permutation between catalyst and membrane. Design and optimization studies will be required to improve the membrane reactor for commercial small-scale operations, especially in sub-Saharan Africa. Therefore, a process is required to simultaneously overcome the shortcom-



**Figure 3.** Schematic diagram of the jet reactor

ings of feedstock and the use of homogenous catalysts with the aid of membrane technology and heterogeneous catalysts. Different chemical reaction processes has been successfully applied using the membrane reactor technology, which suggests an apparent success in biodiesel production. The transesterification of lipids is a classic reversible chemical reaction that could also be combined with membrane reactor technology [49]. These membranes can be either organic in nature (i.e. polymeric) or inorganic, with inorganic membranes being better than the former in terms of their excellent thermal stability [50]. It has also been found out that different pore-sized membranes could retain canola oil using a reactor with a high purity of canola biodiesel obtainable. This method (as shown in Figure 4) has clear advantages over conventional means as it ends with a fatty acid methyl ester (FAME)-rich phase, a controlled contact of incompatible reactants, and an elimination of undesired side reactions. There is also an integration of reaction and separation into a single process, thereby reducing separation costs and recycle requirements, and an enhancement of thermodynamically limited or product inhibited reactions resulting in higher conversions. The FAME-rich phase still contains FAME, methanol, glycerol and water, causing a problem of downstream processing in terms of separation [50, 51]. This work by Dube et al. clearly demonstrates that a membrane reactor can be used to alleviate many of the difficulties highlighted and successfully carry out the transesterification of lipids to biodiesel. Preliminary laboratory testing on the application of membrane technology has also been conducted by a group of researchers in South Africa. The process developed was able to simultaneously overcome the shortcomings of waste cooking oil feedstock and the use of homogenous catalysts with the aid of membrane technology and heterogeneous catalysts. The membrane was remarkably able to block un-reacted feed and impurities from entering the permeate, which gave rise to a higher purity FAME product [52].

### 3.2.5. Reactive distillation technology

Reactive distillation can be applied successfully in biodiesel production as a potent process intensification technique since the reactions leading to the end-product are controlled by chemical equilibrium. This process has been found to be highly advantageous in esterification-

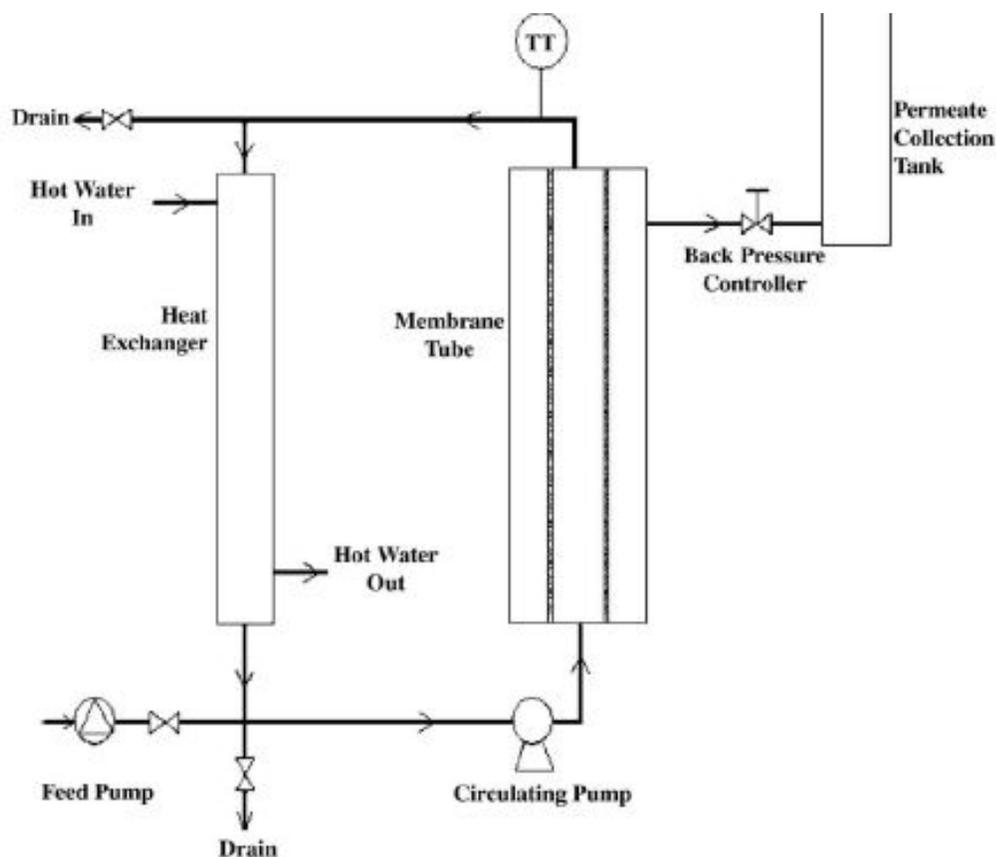


Figure 4. Schematic diagram of a separation membrane reactor [52]

type reactions with high free fatty acid feedstock [53]. The use of excess methanol becomes unnecessary with this method as this can shift the reaction equilibrium towards ester production by continuous removal of the water by-product [54]. An additional flash evaporator and a decanter are used to guarantee the high-purity biodiesel product from multiple feedstocks, which may include a biodiesel reactor, a decanter, a flash evaporator and a distillation column. Since methanol and water are much more volatile than the fatty ester and acid, these will separate easily at the top [55]. Researchers have considered various aspects of this technique, including optimization of reaction conditions, heat integration, use of thermally coupled distillation columns [56] as well as dual reactive distillation processes [56] with respect to biodiesel catalysis. A complex distillation column with a side rectifier has been shown capable of carrying out a reactive distillation process for the production of biodiesel as demonstrated in a novel integrated reactive separation process for FAME synthesis (Figure 5). This integrated biodiesel process is based on reactive separations powered by heterogeneous catalysts offering significant advantages such as minimal capital investment and operating costs, as well as limited catalyst-related waste streams and eliminating soap formation. This novel technology reported efficiently uses the raw materials (including low-cost feedstock, i.e. waste cooking oil) while considerably reducing the energy requirements for biodiesel production—85% lower compared to the baseline studies [57]. Using pure free fatty acid as feedstock, Kiss et al. [54] report an energy saving of up to 45% due to heat integration inclusion and a significant reduction in steam consumption in the raw material pre-heaters. This process presents the

following advantages over conventional biodiesel production processes, shorter reaction time, high unit productivity, no additional alcohol requirement, lower capital and operational costs (due to the elimination of additional separation units as a single column is adequate), elimination of neutralization and separation steps of catalysts when solid acid catalysts are used. It also offers additional substantial advantages, such as higher reaction rate and selectivity, avoidance of azeotropes and reduced energy consumption as well as solvent usage [51]. The apparent advantage that this method has over other methods of processing biodiesel stimulates further study, especially for continuous high-volume production in sub-Saharan Africa.

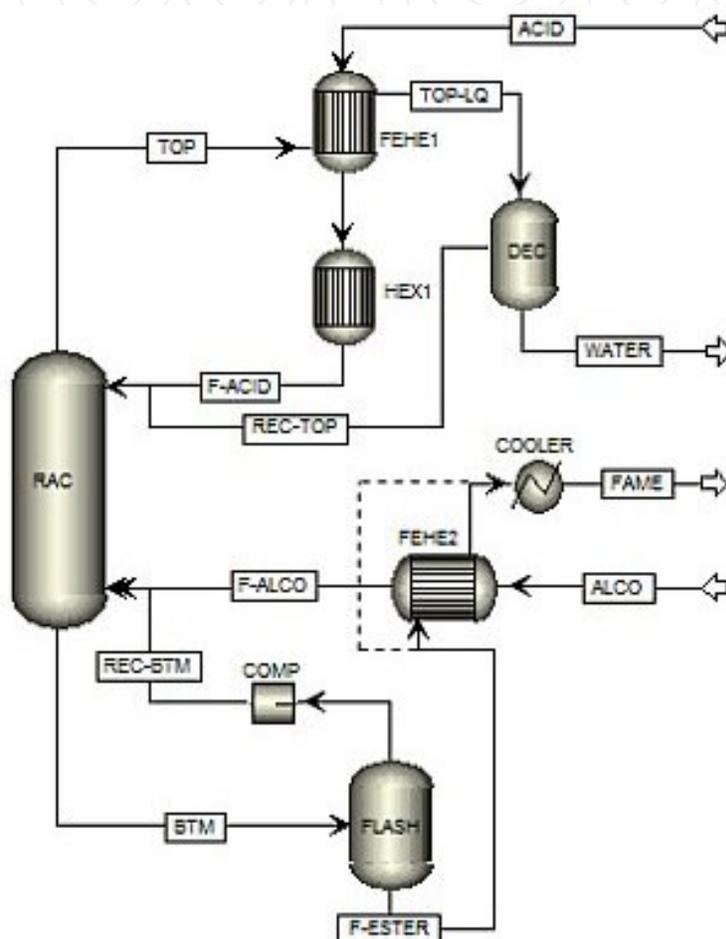


Figure 5. Schematic diagram of an integrated reactive separation process for FAME synthesis [57]

#### 4. Feedstock: Potential and requirement

A major strategy to ensure the sustainability and success of the biodiesel industry is reliant upon the availability of adequate supplies of reasonably priced feedstock. Raw material being the main driver in determining the total production cost of biodiesel, there is therefore need to focus attention on the type, availability and the use of raw materials (which include

vegetable or animal fat and oils). Another issue to contend with is the competition between food production and energy production as strong views are expressed in research and academic circles. In order for the production of biodiesel to be sustainable in sub-Saharan Africa, the choice of feedstock must correlate with the availability of such in specific environments. A brief biofuel potential in the SADC region of Africa is presented in Table 1. The various potential feedstock for biodiesel production that are currently available in southern Africa, which can be considered suitable, include but not limited to cashew nut, sesame seeds, castor oil, pumpkin, rapeseed, avocados, coconut, soybean, cotton seed, sunflower and maize. A highlight of a few of these feedstocks is done in the following sections.

Country	Population (million)	Land size (million Ha)	Forest area	Forestry (%)	First generation biofuels	Next generation biofuels	Potential for next generation biofuels
Angola	12.53	124.67	59.104	47.41	●		●
Botswana	1.84	56.673	11.943	21.07	●		●
Comoros	0.73	0.217	0.005	2.30			
Congo D.R.	66.52	234.541	133.610	56.97	●		●
Madagascar	20.04	58.704	12.838	22.08	●		●
Malawi	13.93	11.848	3.402	36.16	●		●
Mauritius	1.27	0.204	0.037	18.23	●		●
Mozambique	21.29	80.159	19.262	24.57	●		●
Namibia	2.09	82.542	7.661	9.31	●		●
South Africa	43.79	121.991	9.203	7.58	●		●
Swaziland	1.13	1.736	0.541	31.45	●		●
Tanzania	40.21	94.509	35.257	39.90	●		●
Zambia	11.67	75.261	42.452	57.11	●		●
Zimbabwe	12.38	39.058	17.540	45.34	●		●
TOTAL =	251.55	860.479	352.863	41.01	●		●

**Table 1.** Status of biofuel potential in SADC region [58]

#### 4.1. Canola

Canola oil is an efficient biodiesel feedstock with excellent cold-flow properties due to the low saturation of its triglyceride content. About 44% oil can be extracted from the canola seed when crushed as compared to only 18 % for soybeans; a relatively popular biodiesel feedstock and 30% for sunflower. A great advantage that the use of canola as a feedstock source offers is that nothing goes to waste. The oil cake, which accounts for about 60% of the by-product, can be

used as a protein-rich animal feed and the leftover glycerol from the oil can be used in producing soaps, cosmetics and other personal care products. ELIDZ is embarking on a canola-based biodiesel project together with the Eastern Cape Development Corporation, AsigSA along with the Department of Agriculture [59]. The project is expected to generate a number of jobs in the rural areas. Canola has the advantage of being a nitrogen-fixing winter crop, which can be alternated with maize, thereby increasing the maize yields, which would have the added benefit of increasing food security. On the topic of food security, a larger proportion of maize, which is currently excluded from biofuel production, can be utilized in the food production process as animal feed at a lower cost (since the raw product has already created other income and requires less transportation) and could additionally result in lower meat production costs.

#### **4.2. Sunflower and soybean**

Other biodiesel feedstock sources include the sunflower and soybean and they are extensively cultivated in the South African Development Community (SADC) region of Africa. Their impact on employment is high as they are generally grown by both large and smallholder farmers for food crop or as industrial crops for small- and medium-scale enterprises in biodiesel [60]. This expanded use for the biodiesel industry creates surplus demand and encourages large productions. With respect to yields, sunflower offer greater yields but at a higher price than soybean as yields are highly influenced by seed selection, plant density as well as pest and weed control.

#### **4.3. Jatropha**

Jatropha is regarded as a bio-energy feedstock without adequate scientific knowledge on the shrub and this has resulted in disappointed farmers in countries like Mozambique and Zambia, where out-grower schemes have failed [61]. Southern Africa's climatic conditions favour the production of a wide range of bio-fuel feedstocks but a study on preferred feedstocks carried out by WWF in five SADC countries prioritized Jatropha, sweet sorghum and sugarcane [62]. Jatropha was the most preferred feedstock largely because of its portrayal as a "miracle crop" that grows on marginal soils with limited to no management. The shrub grows wild but can be cultivated for bio-diesel production. It is drought tolerant, suited to well-drained soils and survives on a wide range of terrains and soil types. Its seed oil and other vegetative parts are, on the other hand, poisonous [63]; however, high temperature treatment can reduce toxicity. Oil from the seed can be processed into bio-diesel, soap and candles. In Malawi, Zambia and Zimbabwe, Jatropha is grown as a live fence/hedge by smallholder farmers. It has been established under plantation conditions by private companies in countries such as Mozambique and Tanzania. However, it poses a number of challenges. Its commercial cultivation is yet to take off and very few large-scale commercial plantations have been harvested, processed and reported [64]. It is worthy of mention that Jatropha's agronomic requirements, seed yields and economic returns are largely unknown. The political position towards Jatropha, however, has been strengthened by a national government initiative to support bio-diesel production while the benefits from job creation as well as the use of the end product could come in very

positively, particularly for farmers. In addition to the oil produced from *Jatropha*, the cake remaining after the seeds are processed is a good organic fertilizer after composting it and can be used to make paper, cosmetics, toothpaste, embalming fluid, and cough medicine, among other items as well. One concern however is that the seeds are highly flammable and therefore the process should not be located near to any sugar or paper producing operations.

#### 4.4. Algae

Algae can be grown using waste materials such as sewage and without displacing land currently used for food production. The production of algae to harvest oil for biodiesel has not been conducted on a commercial scale, but the potential is promising. This “second generation” biodiesel feedstock has the potential to dramatically expand the resource base for the production of biodiesel in the future, hence contributing to solving complications of air pollution from CO<sub>2</sub> and alleviating crises of food competition through energy production. A comprehensive study by Thurmond [65] found that algae and the potential of microalgae as an alternative and sustainable energy source may offer an immense resolution to meeting large-scale and sustainable feedstock supply in developed continents like North America, Europe and Asia, which may thereafter be applicable to Africa. Recent reports show that a genetically engineered bacterium developed by scientists in the United States can produce ethanol biofuel from coarse, wild growing switch grass rather than using vital food crops such as maize [66].

#### 4.5. Waste oil

Recycled oil is a primary feedstock used for the production of biodiesel in most small- to medium-scale biodiesel plants in Southern Africa; however, its insufficient availability presents a big limitation to a large-scale biodiesel production process. Due to the numerous usages of recycled oil (e.g. yellow grease), its collection for use as various other potential feedstock (for the manufacture of soap, cleansing creams, inks, glues, solvents, paint thinner, rubber, lubricants and detergents) makes it highly competitive. The promising potential of using recycled oils as a livestock feed additive has also been identified as it makes livestock feed look fresh and lubricated while also reducing wear and tear on milling machinery. It is worthy of mention to note that apart from quantity constraint, the quality of the oil could have a knock on effect on the quality of the biodiesel produced [67]. A viable biodiesel industry in southern Africa cannot survive primarily on recycled oils due to their limited supply and availability. To meet the long-term feedstock need of the industry in southern Africa, a dedicated biodiesel oil-seed will need to be identified and developed. It is proposed that the best (monopolistic) feedstock should be one that empowers all players across the board from small to large, at the same time a breeding ground for sustainable biofuels industry.

### 5. Conclusion

In light of the discussions and review presented in this chapter, it is critical for indigenous biodiesel industry to continuously improve on aspects that will strengthen its prospects with

respect to better market penetration and production technologies. Having highlighted specific issues related to newly improved biodiesel production processes that could be effectively utilized, It is important to note that there still exists a significant discourse as to the sustainability of a single feedstock to sufficiently supply or meet national biofuel /biodiesel targets however seemingly realistic that target may seem. Challenges brought about by the unavailability of suitable land for the cultivation of a single feedstock as well as competing demands from other important areas (like food and forestry) preclude such production targets. Biodiesel as the most promising substitute for conventional fossil diesel is dependent on the availability of an array of feedstock that offers the following advantages; wide geographic diversity, better resilience to natural disasters and other production shocks. Conclusively, intensive research on providing improved technologies to provide possible advancement to enhance sustainable biodiesel development in sub-Saharan Africa is expedient without jeopardizing security, public health or the environment.

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