The Viability of Biofuels in Developing Countries: Successes, Failures, and Challenges

Zentou, Hamid
Department of Chemical and Environmental Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, MALAYSIA

Rosli, Nurul Shafiqah
Department of Civil Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, MALAYSIA

Wen, Cham Hue; Abdul Azeez, Kafel
Department of Mechanical Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, MALAYSIA

Gomes, Chandima*[+]
School of Electrical and Informations Engineering, University of the Witwatersrand, Johannesburg, SOUTH AFRICA

ABSTRACT: *In the last few decades, finding alternatives to fossil fuels has become a hot issue across all international frontiers. The Intergovernmental Panel on Climate Change (IPCC) has shed light on the feasibility of using biofuels to meet the growing energy demand as well as to reduce CO_2 emissions which are a major cause of global warming, especially in the transportation sector. The production and use of biofuels in developing countries have further advantages, including social and economic benefits. On the other hand, the biofuel industry in some developing countries is facing critical challenges related to food security, land availability, production cost, etc. In this regard, several studies have recently been conducted to address these issues, and this paper comprehensively reviews these cases with respect to the successes, failures, and challenges faced by developing countries, such as Brazil, Africa and India, in expanding their biofuel production. It is clear that all the efforts devoted to promoting the biofuel sector are still insufficient to come over the challenges associated with biofuel production despite the achievements realized in some experiences as Brazil. However, the Brazilian experience cannot be spread over other countries. Implementation of policies with regard to the specifications of each country that integrate with the other sector without intersection is highly recommended. Moreover, further efforts are needed from scientists to reduce biofuel production costs, which may promote the biofuel market as an alternative to fossil fuel.*

KEYWORDS: *Biofuel; Challenge; Success; Developing Countries; Bioethanol.*

***** *To whom correspondence should be addressed.*
+ E-mail: chandima.gomes@gmail.com
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INTRODUCTION

Recently, international attention is directed towards biomass as the source of renewable energy. This topic is gaining interest because of global warming and the depletion of resources caused by high consumption of conventional fossil fuels [1, 2]. Mankind faces a serious challenge in maintaining the present levels of technological advancement and economic growth without compromising on the welfare of future generations, an approach known as sustainable development. Moreover, there is a critical need to improve the living conditions of people in developing countries without affecting the quality of life enjoyed by those in developed countries. Thus, biofuels are an effective alternative to fossil fuels, as they are a source of sustainable energy, which will eventually reduce the CO_2 emissions contributing to the global warming effect [3]. Furthermore, biofuel is a viable source of energy for countries suffering from a lack of fossil fuel resources, and the biofuel industry, if developed, can contribute towards economic growth by creating job opportunities.

Biofuel is produced directly or indirectly from natural feedstocks, which include vegetables, raw materials, and animal waste. Bioethanol, biodiesel, and biogas are the most widely used biofuels [4]. According to their feedstock, biofuels may be classified into four generations, namely 1st, 2nd, 3rd, and 4th generations. The first generation of biofuels is produced by fermenting sugars or by the transesterification of fatty oils like corn, soy and palm. All these food crops are rich in sugars, starches, and oils. The second generation of biofuels is made from non-food feedstocks and residues as well as other cellulosic ethanol feedstocks, using a complex pre-treatment process [5]. An example of this generation is *Jatropha (*Mexico *and Central America origin)* *a*-based biofuel. The third generation of biofuels, like the second, is also made from non-food feedstocks, especially algae. Since algae have a much higher yield with lower resource inputs than other second-generation feedstocks, researchers have classified it under a specific category called the '3rd generation biofuel'. On the other hand, the fourth generation of biofuel is aimed at producing sustainable energy as well as capturing and storing CO_2 using genetically optimized feedstocks.

Brazil and the USA are the leading producers of bioethanol, which uses sugar and maize as feedstocks. On the other hand, the European Union (EU), especially Germany, is a leading producer of biodiesel, made from rapeseed. Germany is followed by the USA, which has seen a rising production of biodiesel from soybeans. Whereas, in Malaysia and Indonesia, the production of biofuel is increasing using palm oil as the main source of energy crops.

Basically, this work will focus on biofuels in developing countries by reviewing and summarizing various articles and studies in order to answer the following questions:

- What is the viability of biofuel production in developing countries?
- What policies are in place to promote the biofuel sector in developing countries?
- What are the achievements of the biofuel production industry, and what challenges and problems does this industry face?

INFORMATION ANALYSIS

Overview of Biofuel Production in the World:

The history of biofuels is closely linked to that of fossil fuels. During the interwar period, oil and gasoline were available only in limited quantities. Therefore, it was critical to look for an alternative source of energy to run the economy. The solution at that time was the gasifier application, a device that used combustible solids like wood, charcoal or anthracite to produce a combustible gas, which could feed the explosion engines and boilers. After the oil shocks in the years 1973 and 1979, the world was interested in increasing its biofuel production. Many studies in this field were conducted during the late 1970s and early 1980s. However, due to a decline in oil prices in 1986, interest in biofuels fell instantly. Finally, in early and mid-2000s, with a new rise in oil prices and a fear of peak oil, the fight against global warming and the fears about the stability of some fuel producing countries have led to a rise in support for the biofuel sector.

There are two main industrial sectors in biofuel production, namely bioethanol, and biodiesel. Bioethanol can be produced by the fermentation of sugars, whereas biodiesel is derived from vegetable or animal fat through the process of transesterification. Currently, global biofuel production progressively increases year per year. Brazil and the USA are the two largest biofuel producers

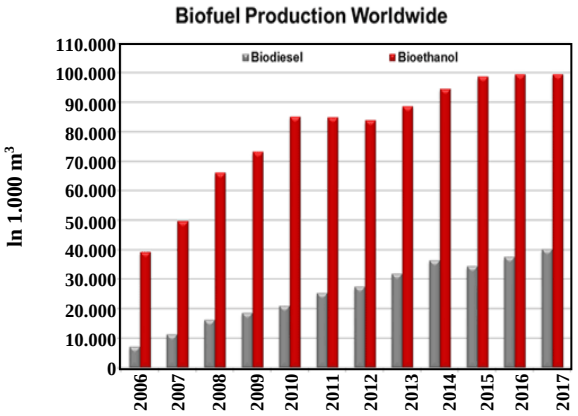

***Fig. 1: Biofuels production in the world per thousand m³* [6].**

in the world. They have both received immense support for the development of biofuels through measures such as tax exemptions and regulatory arrangements. On the other hand, the EU has also encouraged the development of biofuels since the year 1990. Fig 1 represents the global production of the biofuel sectors of bioethanol and biodiesel in the world.

The worldwide biofuels production had shown a remarkable increase between 2006 and 2010 from 39 million m^3 in 2006 to 85 million m^3 by the end of 2010. A fluctuation in the global biofuels production was noted in the period between 2010 and 2015. In 2016, the world production of bioethanol remained at the previous year's level of 117.7 (117.5) million m^3. For 2017, global production is expected to remain stable at 117.6 million m^3.

Biofuel in Developing Countries: Success

In industrial countries, there are high expectations for bioenergy and biomass, as they are seen as safe, environmentally friendly, and CO_2-neutral substitutes for fossil fuels. Moreover, developing countries such as Brazil, South Africa, and Indonesia believe in biofuel production, as it can provide high export income as well as valuable employment opportunities in rural regions [7]. The availability of cheap labour, biomass deposits, and arable land are advantageous factors that promote biofuel production in these developing countries [8]. The biofuel sector was also a key for these countries which are seeking energy security to diversify energy resources. It has also played an important role in developing countries as efficient exploitation of natural resources to create job opportunities for sustainable development and improved livelihood in rural communities. Furthermore, several studies have indicated its potential to reduce the global warming effect and Green House Gas (GHG) emissions [9].

Biofuels are being supported by many governments for a range of perceived benefits [10]. Several developing countries have adopted mandatory biofuel policies and set biofuel targets [11]. In another context, each country has its own constraints, potential, goals, and strategies; thus, national biofuel initiatives, such as the ethanol and biodiesel programs in Brazil, cannot necessarily be replicated in other countries, but, rather, can be viewed as a paradigm to be considered and adopted. In all cases, to ensure that efficient productive routes are adopted, it is essential to take the involvement of stakeholders and an assessment of sustainability into account [12]. Some countries have achieved significant progress in this context, taking the ideal investment of their natural resources into consideration. In this part, we shed light on the Brazilian biofuel industry and its effects on different areas of the economy.

Brazil is a pioneer in the production of biofuel. Using biofuel is driving the country to stop all its oil imports in order to become completely energy independent, and to show the world the potential of biofuel as an alternative choice for fossil fuel. The Brazilian experience has achieved immense success and has motivated other countries, such as the USA, to develop strong biofuel industries based on Brazilian biofuel policies [11]. According to the FOA statistics, renewable energy represents 45% of all energy used in Brazil, comprising the combined use of hydroelectricity (14.5%) and biomass (30.1%); sugarcane as feedstock for biofuel production in Brazil represents 32.2%, which equals 14.5% of total energy produced in the country [13]. After the USA (6921 million gallons from sugarcane in 2010), Brazil is known as the second largest bioethanol producer and the largest bioethanol exporter in the world. Bioethanol production in Brazil increased from 8 to 12 Mio t in the period between 2000 and 2004[14]. An increase in bioethanol production compared to that in 2014 was of 5 %, with the total Brazilian bioethanol production reaching 26.9 million litres. The ethanol export for 2015 is 1.8 billion litres, up 200 million litres from 2014. The Brazilian government turned its attention

towards the biodiesel industry, which was recently regulated to increase biodiesel blend requirements to 6% effective July 1, 2014, and to 7% effective November 1, 2014. As a result, biodiesel production for 2015 is projected at 4.4 billion litres, up 900 million litres from 2014 [15].

In the past, public policies have played a decisive role in developing a strong biofuel industry in Brazil by reducing the risks and encouraging investment and innovation. Brazil has been using bioethanol as a petrol additive since the 1920s, but it was only in 1931 that the fuel produced from sugarcane was officially blended with petrol [13]. Meanwhile, pure ethanol has been used since 1975 and, nowadays, flex-fuel cars are widely in use. In 2008, ethanol production reached 28 Mm^3, but recently, the government's efforts to reduce gasoline prices resulted in reduced ethanol demand. In turn, biodiesel blending was launched in 2005, and B_5 has been mandatory since 2010. In 2011, the land dedicated to the cultivation of biofuel crops was 8.82 Mha or 11.8% of the total cultivated area. A considerable fraction of the land is available, considering improvements in cattle breeding and agroecological zoning for bioenergy [12].

The biofuel industry plays a significant socio-economic role in Brazil. Ethanol is one of the mainstays of the Brazilian economy, although it has recently been impacted. Over one billion dollars have been assembled from investors across the world as investments into Brazil's biofuel sector. The investments will focus mainly on ethanol and electricity production [16]. The table below shows the ethanol exports for 2015 and 2016 (January-June), as reported by the Brazilian Secretariat of Foreign Trade (SECEX).

There is a strong relationship between the biofuel industry and agriculture, especially in the sugarcane sector. Moreover, several studies have noted the relevance of employment and income generation associated with biofuel programs in developing countries and their positive impact on food security and living conditions [18]. Based on data provided by PNAD (2011), the proportion of workers formally employed in the Brazilian agricultural sector is very low (40%), whereas the sugarcane sector shows the highest rate of employment, with 80% of employees being formally hired, and enjoying all the labour rights established in the legislation [19]. The wages in Brazil's sugarcane sector are considerable, which, in turn, optimizes the living conditions and promotes the development of rural zones. The following graph indicates the monthly wages in the sugarcane and other crop sectors. The monthly wages in the soya sector seem to be the highest, but, after accounting for other variables influencing the wages, such as schooling, age, region, gender, etc., the average monthly wages of workers in other crop sectors as compared to those of sugarcane workers are: coffee (9.90% lower), cassava (23.2% lower), corn (30.1% lower), rice (30.1% lower), and soya (0.2% lower) [20] (Fig 2).

Challenges of biofuels in developing countries

As previously mentioned, the biofuel industry is key in the development of Third World countries through the creation of job opportunities, especially in rural areas; by lowering their dependence on fossil fuels to reducing the high cost of imports; and as an eco-friendly source of energy, reducing carbon dioxide emissions [21]. Therefore, biofuel has become one of the topmost agendas for both developing and developed countries, and the world's biofuel production is expected to rise fourfold by 2020 [22]. However, there are various barriers that have become significant challenges in the utilization of biofuels for world production, especially in developing countries.

One of the most debatable subjects in developing countries is the issue of land availability. In Africa, for instance, the ambiguity of land rights has always led to disputation among the involved parties, and the potential development of the biofuel sector could lead to an increase in demand for land, thus aggravating this problem. Meanwhile, in India, the available cropland will most likely be used for food production than for the cultivation energy crops due to the steadily growing population. Consequently, the availability of suitable land for the cultivation of biofuel feedstocks appears to be highly uncertain in the foreseeable future [23].

Another point of criticism related to the production of biofuels is the issue of food security. Concern regarding the fuel resources, which compete directly with food supplies, was also raised, as this could result in food shortages and an increase in food prices, thus conflicting with the low purchasing power in these countries. It is undeniable that biofuels can increase energy security,

Table 1: Brazilian Ethanol Exports (Brazilian Secretariat of Foreign Trade [SECEX]) [17].

Brazilian Ethanol Exports (NCM 2207.10, 2207.20.11 & 2207.20.19, 000 Litres, MT, US$ 1,000 FOB)						
Country	CY 2015			CY 2016 1/		
United States	925,801	732,292	451,034	447,893	353,998	231,503
South Korea	464,771	375,450	213,459	384,300	310,436	174,030
Japan	48,914	38,609	26,183	58,225	46,050	29,948
Netherlands	63,560	50,909	27,945	46,825	37,826	20,617
India	91,547	74,046	36,392	44,356	35,868	15,535
China	120,255	95,417	54,212	35,320	28,092	16,115
Nigeria	46,370	37,475	19,908	22,375	18,097	8,871
Turkey	19,317	15,557	9,026	12,859	10,348	6,157
United Kingdom	15,998	12,635	7,940	8,145	6,429	3,946
Angola	4,879	3,819	3,386	5,875	4,707	3,133
Others	65,786	65,786	30,990	17,250	13,999	10,237
Total	1,867,199	1,489,408	880,475	1,083,423	865,849	520,091

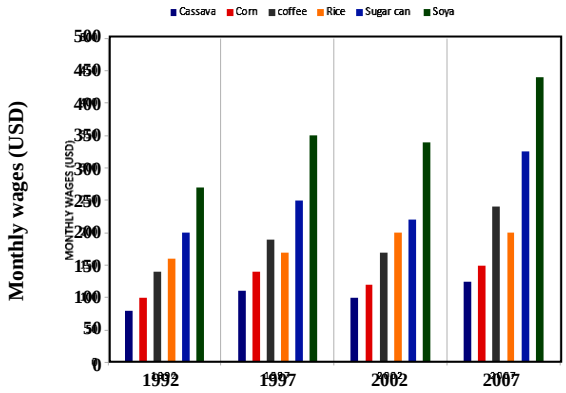

Fig. 2: Comparison of monthly wages in different crop sectors in Brazil [20].

help in reducing GHG emissions, increase the air quality in cities and spur growth in rural areas. Nevertheless, several risks or problems that come along with biofuel development (such as the replacement of natural forests with biofuel crops; spreading of monoculture; water scarcity; decreasing water quality; soil degradation; and potential conflict with food production) are becoming a challenge to the efficient use of biofuel for world production [24]. The specific challenges will be discussed further in relation to African countries and India.

A wetland is a land saturated with water, which has fertile soil and is suitable for cultivation. Moreover, wetlands are considered as a source of fresh water and fish for the local residents in Africa. Although only 4% of African wetland covers the total landmass, the holds more than half of the world's liquid freshwater. In Europe, North America and Latin America, a lack of suitable land and the changes in climate make the cultivation of biofuel crops unfeasible. Africa hasan abundance of cultivable land, a favourable climate, and cheap labour. Hence, the 70 million hectares of African wetland is used for the production of biofuel feedstock, leading Africa to become one of the leading suppliers of biofuel crops to the European nations, apart from Brazil. However, Africa's wetland is also a host for a broad array of wildlife species and plays an essential role in the migration of birds between Europe and Asia. With the development of biofuel crops, large-scale irrigation, drainage, and pollution have occurred in Africa's wetland [25].

In Africa, biomass is the most important source of energy and is used for domestic purposes. The biofuel production in Africa is concerned more with industrial rather than vehicular usage. Malawi, for example, has produced bioethanol since 1970, but the production was on a small scale. Instead of planting sugarcane, Africa is focusing more on the cultivation of *Jatropha*. At the beginning of 2008, a market study identified 97 *Jatropha*

projects, with 119,000 hectares of land under cultivation and with upcoming plans for an additional 2 million hectares by 2015 [26].

However, the investment plans and the existing projects are geared towards an export market, while the greatest demand for biofuels is in Europe and North America. The truth is, the interest in biofuel production in Africa is not for meeting the energy needs of Africans, but, rather, is geared towards meeting the energy demands and extenuation commitments of industrialised countries [27]. This is because biofuel production is not the main issue or problem in Africa; there are more pressing concerns in the country, such as economic, food consumption and health issues, which require urgent attention. Hence, there are a few key challenges in the production of biofuel and biodiesel in Africa, including food sources, land usage, and the economic problem.

One of the challenges of biofuel production in developing countries, especially African countries are the influence of the biofuel sector on food resources. Basically, ethanol can be produced from sugarcane, maize, sweet sorghum and cassava, while biodiesel can be made from oil palm and *Jatropha* [25]. The cultivation of these food crops will eventually require large tracts of land in order to implement large-scale biofuel production. Therefore, instead of being reserved for food production, much of the land is being utilized for the cultivation of energy crops. In the East African region, specifically in Tanzania, 112,000 acres of land are used for *Jatropha* production, initiated by Britain's CAMS group. Moreover, Sun Biofuels have also bought about 13,500 acres of land in Tanzania for *Jatropha* production [28]. In other words, the resulting decline in crop production has caused millions of Africans to face starvation, with rural communities being affected the most. Hence, the most crucial step in Africa is to bring the increment of feedstock production to a sustainable level to make room for meeting food requirements.

The other challenge arising in biofuel production is the issue of land sources. As mentioned earlier, a large area of land is required for cultivating the energy crops for biofuel production. Without any consideration of the loss of biodiversity, the developers cleared the arable land and wooded area in Ethiopia [29]. Apart from the effect on biodiversity, the water used by the locals was also significantly reduced, as water is needed in biofuel production for mixing, washing and evaporative cooling. For instance, the *Jatropha* plant, which grows well in semi-arid areas, requires a large amount of water for irrigation, so the developers prefer to use the water resources for the biofuel crop rather than for food production [30].

According to what the previous studies have reported, one purpose of using biofuels is to mitigate air pollution by reducing the emission of greenhouse gases. However, biofuels might release more greenhouse gases than they help to conserve. The destruction of natural ecosystems will occur because the cultivation of biofuel crops requires large areas of land. Meanwhile, the net GHGs released from biofuels vary from case to case and are still under analysis. Hence, whether or not biofuel can effectively reduce the emission of greenhouse gases still remains a key concern in its implementation.

On the other hand, India is the world's fifth largest energy consumer and is expected to become the third largest by 2030. Its rapid urbanization, industrialization and economic growth have increased the energy requirements, resulting in a dramatic rise in oil imports from 21 million tons since the early 1990s to 111 million tons in 2006-07 [31, 32]. This energy demand is very substantial for developing and emerging economies, such as India, in maintaining their societal metabolism, and it is expected to increase unceasingly (Ariza-Montobbio and [31, 32, 29]. In addressing the concern about energy security, the Indian government has promoted biofuel as an alternative energy source by making it obligatory to blend gasoline with biofuels, aided by a policy incentive designed to facilitate optimum development and exploitation of indigenous renewable biomass feedstock [35]. The other reasons behind biofuel promotion in India include the mitigation of climate changes due to the emission of Green House Gases (GHGs); environmentally sustainable development; and increased opportunity for new employment [36]. In 2003, the National Mission on Biofuel was launched by the Indian government in two phases with specific targets, (i) the cultivation of 400,000 *ha* of land, the establishment of research networks in 42 public universities, and the achievement of a 5% blending target (phase I); and (ii) the achievement of a 20% blending target by 2011-2012 (phase II) [37].

Throughout this program, *Jatropha curcas*, which is known to have a high oil content (40% by weight),

was selected as the primary feedstock from among 400 non-edible oilseed crops available in India, and it has been regarded as a promising crop for securing energy supply and socioeconomic development [37,38]. *Jatropha* has also been acclaimed for its alleged capability to resist pests and to yield well even on degraded soils, under water stress, and without the application of fertilizer [39]. Moreover, the use of inedible vegetable oils as biodiesel feedstocks can offer an alternative for the existing edible resources [40], competing economically with the petroleum-based diesel fuel, as the production costs of biodiesel can be reduced by using cheaper, non-edible vegetable oils.

To achieve the 20% mixing target of biofuels, a recommendation to plant Jatropha on 17.4 million *ha* of degraded wasteland was proposed [37], and a biodiesel purchase policy was announced by the Ministry of Petroleum and Natural Gas (MoPNG) in 2005, where the purchase price was set at Rs. 25 per litre. However, due to the higher cost of biodiesel production, exceeding about 20%-50% of the set price, it resulted in no sale for biodiesel. The major factors leading the higher biodiesel production cost include the increase in salary rates; the unavailability of feedstock resources; and incompetent marketing channels. *Kumar et al.* presented the status report of the National Biodiesel Mission in 2003[41]. According to them, the National Biodiesel Mission for phases I and II was a failure, as none of the mission's targets has been achieved due to a lack of *Jatropha* seed cultivation to produce biodiesel. In addition, despite claims regarding the advantages of *Jatropha* as a source for biodiesel [34], the reality was very far from the expectations. The ability of *Jatropha* to yield under suboptimal growing conditions seems to have been highly overrated. Kant and Wu reported that *Jatropha* indeed grows wild in many hot, dry areas with low productivity [42]. However, the insufficiency of moisture and nutrients were reflected in lower seed production, as the production of the *Jatropha* seed can be affected by moisture content, temperature, and soil fertility.

Axelsson et al presented a case study on the performance of the *Jatropha* biodiesel production in Southern India [38]. The study showed that 85% of the farmers have stopped their *Jatropha* cultivation due to several barriers, such as climate changes, water scarcity, insufficient yields, labour costs, insufficient income from the plantation, lack of support from the government in terms of subsidies, as well as the unfulfilled promises made during the initial phase. The failure to reach a satisfying yield is the main problem encountered in *Jatropha* cultivation, thus presenting a challenge to the commencement of large-scale *Jatropha* plantation. The cultivation of *Jatropha* under poor conditions has failed, and the yield did not achieve the expected level even when fertilizer was applied and the plantation properly maintained. The 5-year gestation period for *Jatropha* cultivation results in a lengthened payback period, thus creating additional problems for farmers who are unable to avail state support. Basically, there will be no economic yield for *Jatropha* in the first three years of the plantation, and most of the farmers remove their plantation within that period. Hence, instead of gaining income from *Jatropha* cultivation, many farmers are experiencing financial losses and insufficient incomes.

Kumar et al. reported other major hurdles in realizing the biodiesel program, which then leads to the failure of both phases of the National Biodiesel Mission. Firstly, in India, there is a lack of attention given to addressing the technological issues interrelated to biodiesel usage in the current petrol-diesel engines in terms of R&D laboratories, companies associated with the oil industry, and the main manufacturers of petrol-diesel engines. In order for biodiesel to be accepted in the automobile industry, certain technological complications and issues need to be addressed as well [39]. Some of the issues being constantly raised are the oxidation throughout the storage period; deficient lubrication properties; and difficulties in starting during cold weather [43]. Thus, some serious initiatives on the part of the government are necessary to address all the potential technical issues obstructing the use of biodiesel-based diesel engines. A lower amount of excise duty on such diesel engines should also be offered to compensate for the supplementary research initiatives or the production costs involved in the modification of the engines.

Secondly, there is no institutional provision under the National Biodiesel Mission, which was established to produce high quality *Jatropha* seeds that could result in high oil yield. In developing high quality seeds, it is very important to have institutional funding and an allocation of wasteland through the involvement of private players,

as well as an insurance mechanism for biofuel crop plantations, including *Jatropha*, against the yield risk. However, due to the absence of plantation insurance, the number of players involved with an assurance of long-term earnings in the form of seed harvests as well as the production of oil and biodiesel is very limited.

Last but not least, the absence of financial support and subsidies is one of the main reasons for the failure of the National Biodiesel Mission. In any biofuel policy, budgetary support should be a fundamental part of biofuel cultivation to support livelihoods during the *Jatropha* gestation period. Furthermore, in order to ensure feasible biodiesel pricing, component subsidies are required, along with subsidies on biofuel crops and tax credits on energy crops. These barriers have resulted in the failure of the biodiesel program, while also limiting the commercial application of advanced biofuel technology in the near term. Moreover, despite having vast potential, large-scale deployment of advanced biofuel technologies is still debatable for the upcoming future, unless there is further advanced research and development that lowers the existing barriers and challenges [44].

CONCLUSIONS

Undoubtedly, biofuel plays an important role in the future, as it is a viable replacement for fossil fuel in current use. Apart from energy security, it is important in minimizing environmental pollution by reducing the production and emission of GHGs, which are a direct cause of global warming. Moreover, as biofuels can be produced directly or indirectly from natural resources, such as animal waste and plants, large quantities of raw materials would need to be planted as energy fuel to implement large-scale biofuel production. This will serve to create job opportunities for villages and rural communities, which indirectly helps in the growth of the country's economy.

On another hand, Biofuel production requires a long-term commitment in order to get the benefits, and its minimum-level profits make it challenging for cultivators, farmers and rural residents to fulfil their daily living expenses. Moreover, as the cultivation of biofuel crops requires large tracts of land, this will eventually reduce the availability of grazing land, which is a food source for livestock, and will lower the production of food crops, especially in developing countries like Africa and India. In addition, the lack of government initiatives and support in these countries is one of the main challenges facing the development of the biofuel industry. Furthermore, as theb iofuel is a relatively new product in the market, a lot of research is needed to overcome the challenges arising from biofuel production in developing countries.

Despite the success has been achieved in the biofuel sector especially in Brazilian experience, critical issues are still associated with biofuel industry obstruct this sector. The Brazilian experience cannot be spread over other countries. Implementation of policies with regard to the specifications of each country that integrate with the other sector without intersection is highly recommended. No doubt, biofuels could fill some of the gaps left by the depleted fossil fuel resources, while also mitigating the global warming issue. However, the integrated management for biofuel production should be planned wisely, while considering the importance of human needs in order to make progress in biofuel implementation.

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