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Biodiesel: A potential bio-fuel for future sustainability

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ABSTRACT

An ever-increasing demand for an alternative energy fuel resulting from the gradual depletion of traditional energy resources as well as their hazardous impacts on the environment motivates us to explore biodiesel as a promising sustainable solution across the present world. The present article thus attempts to highlight the essential environmental and economic benefits of biodiesels derived from eco-friendly renewable resources. Biodiesels are mostly derived from oil crops through well-known separation techniques like blending, pyrolysis and trans-esterification of vegetable oils and animal fats. The biodiesels thus derived from renewable resources are found to have a lower carbon footprint that can potentially replace commercial non-renewable petroleum fuels currently available in the market. As a sustainable fuel, biodiesels have been explored to apply directly in various fields including industrial and transportation sectors. Besides several advantages and environmental sustainability issues, biodiesels also have some serious disadvantages that need to be resolved before it is used across the commercial global market and these factors also have been incorporated in the present article. The article also attempts to address various policies and government incentives and attempts developed so far to popularize biodiesel as an effective and sustainable alternative across the globe.

Keywords: ***Key words: Biodiesel, renewable resources, sustainability, trans-esterification***

INTRODUCTION

Scarcity and gradual depletion of conventional non-renewable energy resources, such as fossil fuels, along with a steady degradation of the global environment necessitate the invention of alternative renewable green energy resources for a future sustainable world. The whole scientific community across the globe thus has focused on exploring alternative renewable energy resources like Biofuels utilizing cheap raw materials, which not only have the potential to meet the present energy crisis but also offer reasonable economic benefits to mankind. Biodiesel is an important biodegradable, non-toxic and environmentally benign [**1, 2**] biofuel that came into the light in the 1980s and initially became popular in the European Markets, particularly in France and Germany as an effective blend of petro diesel. Later few other countries across the globe, such as the United States, Brazil, Japan and India, started the commercial use of Biodiesel blends as vehicle fuel successfully [**3**]. Biodiesel is chemically composed of mono-alkyl esters of long-chain fatty acids mostly resulting from the trans-esterification process between vegetable oils or animal fats in the presence of a catalyst [**4, 5**]. This particular biofuel exhibits quite similar combustion properties like energy density to regular diesel derived from petroleum and due to having low emission profiles attempts to avoid air pollution hazards by reducing Green House Gas (GHG) emission by 78% as well [**6, 7**]. The analysis of the life cycle from the approach of positive energy balance [**8**] and consideration of potential economic perspectives implicitly includes biodiesel in the category of promising sustainable fuel resources. Moreover, a few inevitable global issues, such as the ecosystem imbalance due to energy crop plantation and negotiation of feed sources with food, support and emphasize the prospect of biodiesel as a sustainable green fuel for the future generation.

HISTORICAL BACKGROUND

The first successful operation of diesel engines that used fuels like water-suspended coal dust, mineral oil and vegetable oil was demonstrated by Rudolf Diesel, a famous mechanical engineer from Germany. After the death of Diesel in 1913, a modified form of Diesel's engine running on polluting petroleum fuel (commercially known as 'Diesel' nowadays) was introduced. During the following two decades, vegetable oils replaced diesel fuel in combustion engines [9], specifically in emergencies. In the following decades, two major global environmental concerns, namely the compensation for the gradual depletion of fossil fuel reserves and minimization of Green House Gas (GHG) emissions to cut out atmospheric hazards motivated the scientific community to explore more effective and efficient eco-friendly energy sources to meet the overall energy crisis across the globe. Though the first-ever trials on the successful implementation of biofuels were demonstrated in the 1940s, when methyl and ethyl esters respectively derived from vegetable oil and palm oil used in France and Belgium to drive bus engines, extensive research on alternative fuels [10, 11] utilizing green resources like fats and oils was sought due to a huge hike of commercial petroleum prices during late 1970s and early 1980s. The wide production of biodiesel resulting from transesterification thus became an important thrust to the present technological developments related to energy fuels started during the early 1990s and steadily developed according to the increasing levels of energy demand [12] across the globe.

COMMON SOURCES AND PRODUCTION OF BIODIESEL

The proper choice of biodiesel feedstocks depends on its availability, costs and production scale which, in turn, is largely influenced by factors, such as the texture and conditions of local soil, agricultural practices, geographical locations and climatic conditions. Though biodiesel can be produced from various renewable feedstocks like neat vegetable oils, polluting waste cooking oils, animal fats and oils extracted from algae, microalgae, bacteria and fungi, more than 350 crops have been identified as the most suitable precursors of biodiesel globally [3, 6,13,14].

Feedstocks of Biodiesel are thus broadly classified into four different categories: Edible vegetable oils derived from soybean, rapeseed, peanut, sunflower, palm, corn, coconut oil etc [15], Non-edible vegetable oils obtained from Jatropha, Castor, Karanja, Rubber seed, *Pongamiapinnata*, algae etc [16, -18], animal fats like pork lard, beef tallow, yellow grease, chicken fat and by-products from fish oils etc. [19] and Waste Cooking Oil (WCO) or recycled oil like grease [20-23] which most importantly eliminates the cost of safe disposal. Another type of feedstock derived from non-traditional bio-energy food crops popularly known as genetically engineered plants or crops like poplar, switchgrass, miscanthus and big bluestem [14, 24] offers simultaneous economic and environmental benefits over traditional food crops [25], especially in the field of biofuels production. Moreover, they increase oil production from the plants (e.g., in corn protein and oil content is enhanced), affect special features (e.g., resistance to drought and diseases are adopted), and minimize unwanted attributes (e.g., genes responsible for methyl bromide-producing in Canola oil is suppressed) [26- 29] for the crops.

To prepare biodiesels, the crude oils are extracted from the suitable feedstock by three conventional methods: Mechanical extraction, Solvent extraction and Enzymatic extraction, among which the mechanical process is the most popular one. On the other hand, a liquid solvent, such as n-hexane, methanol, ethanol or toluene is utilized during solvent extraction process where the rate of oil extraction can be modulated by changing factors like size of the particle, nature of the liquid, temperature and mixing of the solvent. The oil extraction through the solvent method can again be operated in different modes like Hot water extraction, Soxhlet extraction and Ultrasonication technique [30].The Enzymatic extraction technique is also an important approach that uses suitable enzymes, such as Alkaline protease or Lipase to extract oil from vegetable precursors [31].The crude vegetable oils thus extracted are often found to be highly viscous, less volatile and contain polyunsaturations. These associated issues can be conventionally escaped by four different methods, such as direct use and blending (dilution), microemulsions, thermal cracking or pyrolysis and trans-esterification.

Vegetable oil-diesel fuel blends in different ratios (e.g. 20:80 or 50:50) have been explored to be more efficient rather than using pure oil (100%) for engine operation. Though vegetable oils as diesel fuel find several advantages for their liquid nature-portability, significant heat content (about 80% of diesel fuel), easy availability and renewability, but still a couple of disadvantages like more viscosity, lesser volatility and reactivity of unsaturated hydrocarbon chains are also associated with their usages. Moreover, a few other obvious issues like acid composition, free fatty acid (FFA) content, production of gum resulting from oxidation and polymerization while storage and combustion, deposition of carbon and gradual thickening of the lubricating oil restrict pure vegetable oils and/or blends to be used for both directly and indirectly for diesel engines. Though few potential solutions like preheating fuel before injection, partial oil-refining to remove gums, adjusting the timing of injection, using suitable motor oil additives to prohibit oxidation etc are well-known to minimize such problems, the use of pure vegetable oils and their blends for diesel engine operations are still found to yield unsatisfactory results and hence not recommended [9].

Higher viscosity of vegetable oils originating from the formation of microemulsions with solvents like alcohols, e.g. methanol, ethanol, 1-butanol or hexanol prohibits its direct use as diesel fuel. Microemulsions are typically transparent, thermodynamically stable colloidal dispersions composed of optically isotropic fluid microstructures with dimensions in the range of 1-150nm and are spontaneously formed from two immiscible liquids and one or more ionic or non-ionic amphiphiles [32]. Commercially these microemulsions have droplet diameters in the range of 100-1000 Angstrom that result from mixing an ester with vegetable oils in the presence of a co-solvent, typically a dispersant, or vegetable oil, a surfactant, an alcohol, or a cetane improver, with or without diesel fuel. As per the literature reported so far, the maximum viscosity requirement for diesel fuel is found to be satisfied for microemulsions resulting from butanol, hexanol and octanol, e.g. efficient micellar solubilization of methanol in triolein and soybean oil occurs in presence of an amphiphile like methanol.

Another conventional technique to produce biodiesel is thermal cracking or pyrolysis which is essentially thermally induced chemical reaction in the presence of a catalyst inside an inert atmosphere [33], where chemical bonds break to yield small-sized molecules from bigger ones [34]. The thermal decomposition mechanism of triglycerides as depicted by Schwab et al. [35] has been shown in Figure 1. Based on operating conditions, like temperature, residence time, rate of heating and major yields, three important categories of pyrolysis techniques are reported: Conventional or slow pyrolysis, Fast pyrolysis and Ultra-fast or Falsh pyrolysis [36]. Since various reaction pathways and the products obtained during reactions affect the chemical process substantially, pyrolytic chemistry is often found to be complex and difficult to characterize. Though pyrolysis of fats in the presence of catalysts like metallic salts [33] is an older technique that is being utilized across the world, especially at places with low petroleum stock, several materials, such as vegetable oils like Tung oil, soybean oil, safflower oil, copra oil, palm oil etc [35, 37, 38, 39], animal fats, natural polyunsaturated fatty acids[40] and methyl esters of fatty acids [41] are well known conventional sources for biodiesel production during the present time. The equipment that are commercially used for thermal cracking and pyrolysis are often found to be moderately expensive, whereas the pyrolyzates not only exhibit chemical similarities with petroleum-derived gasoline and other diesel fuels but also offer lower viscosity and flash points than conventional petroleum diesel fuels, equivalent calorific values[3], lower Cetane Numbers (CN), the acceptable quantity of sulfur, water, sediments and copper corrosion values[42] and additionally minimize environmental hazards due to air and water pollution [43].

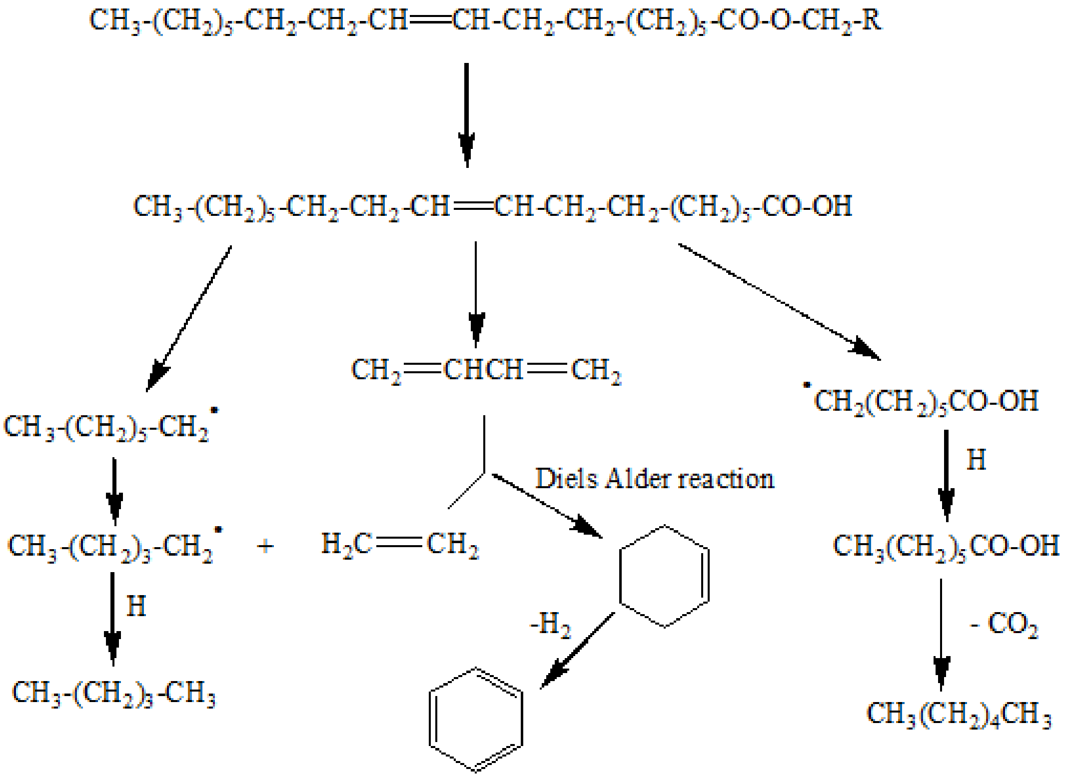

Figure 1: Thermal decomposition mechanism of triglycerides

Commercial biodiesel production involves transesterification or alcoholysis of fats or oils (triglycerides) with alcohols (e.g. methanol) to produce biodiesels (shown as fatty acid esters) and glycerol (**Figure. 2**). The chemical reaction proceeds through a reversible mode where the catalyst, such as alkalis (e.g. NaOH, KOH, carbonates and corresponding alkoxides), acids (e.g. Sulfuric acid, sulfonic acids and hydrochloric acid) [**44-47**]and enzymes (e.g. Lipases) [**45**, **48**],

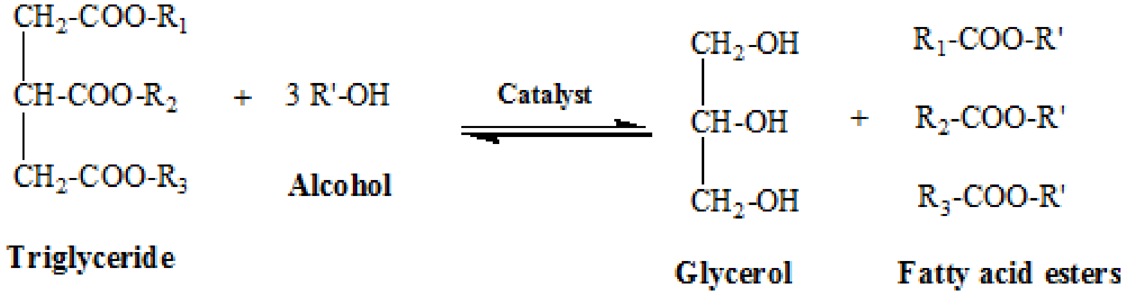

Figure 2: Trans-esterification of triglycerides with alcohols

improves the yield and reaction rate where the excess alcohol shifts the equilibrium to the final product side. Mostly monohydric alphatic alcohols with one to eight carbon atoms like methanol, ethanol, propanol, butanol and amyl alcohol etc are used in the alcoholysis that involves a three-step mechanism (**Figure 3**). The biodiesel is then recovered from the mixture after the removal of glycerol and methanol by a repeated thorough washing of the reaction mixture with clean water. Several important factors, such as free fatty acid (FFA) and moisture content of the reaction mixture, the stoichiometric molar ratio of alcohol to triglyceride, the mode of catalysis and catalytic efficiency, reaction temperature and operation time etc influence the conversion yield of

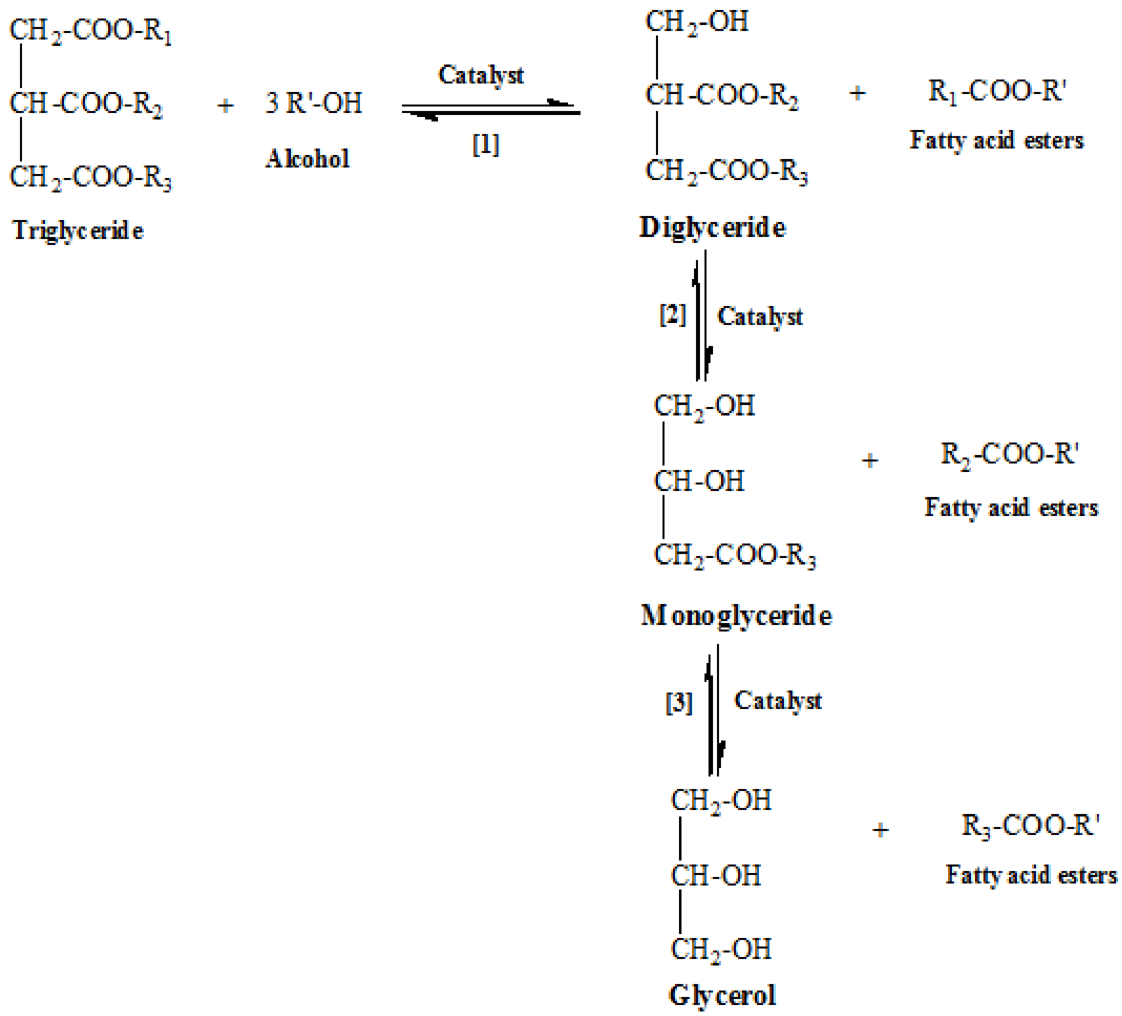

Figure 3: 3-step mechanism for trans-esterification

trans-esterification. After the biodiesels are derived from plants of diverse origins, the chemical and physical properties of the diesel that mostly depend on the types of feedstocks and their fatty-acid compositions [**3, 6, 24, 49**] are verified by checking various parameters like viscosity, fuel density, flash, cloud, pour and cold filter plugging point (CFPP), cetane number, oxidation stability, lubricating property, acid value, carbon residue etc. before they are sold in commercial global markets.

PRESENT AND FUTURE APPLICATIONS

Biodiesels are found to be potential substitutes to petroleum-based diesels or petro-diesels [**50**]. Most of the commercial uses of biodiesel involve a blended fuel derived by mixing biodiesel with petro-diesel in different proportions that again depend on factors like the availability and cost of the biodiesel, the choice of engine and its desired performance. Apart from this, the government regulations in the respective countries and the economics of biodiesel production also have a marked influence on the blending ratio.

Diesel engine automobiles are found to be the most popular choice where such blended biodiesels are routinely consumed [**51- 54**]. Considering the choice of origin and the quality of biodiesels with various blends containing varying levels of biodiesels and commercial petroleum-based diesel, the diesel engines are recommended to run by such blended biodiesels by different vehicle manufacturers and companies, such as Daimler Chrysler, Mercedes Benz etc across different countries like Canada, USA, UK and Malaysia. The major oil companies in India either produce biodiesel in their plants or import from other manufacturers located outside India. This biodiesel is then blended with other commercially available petroleum-based diesel and certified to be sold at the retail petrol pumps for diesel engine vehicles.

Like automobile engines, railway engines in many countries still consume petroleum-based diesel as well as its blend with biodiesel [**52, 53, 55**] even after the successful conversion of railway engines to electricity-driven engines to pull the racks. In such cases, either pure biodiesel (B100) or blends with petroleum-based diesel are used as and when recommended. On the other hand, biodiesel also satisfactorily fulfills the requirements of aviation fuel for aircraft and has been routinely used to fly different aircrafts for more than a decade [**51**]. Based on the variety of raw materials including edible oils, specific grade biodiesel commonly known as Sustainable Aviation Fuel (SAF) for aircraft is being manufactured by different companies that have already signed agreements with various commercial airlines to supply SAF across the countries. Several biodiesel blends are also presently being used to drive diesel engines of ocean-going ships on a larger scale and thus essentially offer a promising setback to biodiesel in the application and promotion of cleaner fuels such as hydrogen. A few blended biodiesels are also reported to have specific heating applications particularly to heat commercial as well as domestic boilers efficiently after suitable standardization."Bioheat"derived by blending biodiesel with conventional petroleum-based heating oil, is one of the examples of such specific blends and has registered trademark particularly in USA and Canada in recent times. Unlike other blends commonly used for transportation, these specific blends exhibit slightly different characteristics and are consequently taxed differently. On the other hand, blended biodiesel-based heating oils also need special care as they can have damaging effects specifically on the rubber parts in commercial furnaces.

This issue has been attempted to resolve by utilizing laws and regulations issued by the concerned government authorities. Biodiesels without blends (B100) also find potential applications in driving power generators mostly in thermal power generation plants, agricultural machinery, like tractors, and various agricultural processor equipment nowadays. This effort not only ensures an overall decrease in air pollution by minimizing the emission of air pollutants such as carbon monoxide and particulate matter (PM) but also efficiently eliminates the byproducts of petroleum-based diesels that yield smog, ozone and sulfur emissions and consequently degrade the air quality. Thus production of biodiesel from different indigenous raw materials to drive power generators by augmenting the scarcity of the supply of electricity has become an important trend majorly in remote areas in countries like India. Apart from these, biodiesel also is very useful as a significantly good tool for the process of crude oil spill cleaning particularly on high seas and near shorelines. Since biodiesels have better buoyancy and lower viscosity than various crude oils, an effective removal of crude oils from the shoreline by the tides is easier particularly when the crude oils are specially coated with biodiesels. After the removal of the coated crude oil from the shoreline into the ocean, manual skimmers can efficiently remove the mixture of oil and biodiesel on the water surface while the residual undergoes easy biodegradation. Due to important solvent characteristics, biodiesels can also be used in the removal of paints and adhesives. Biodiesels also find their applications as a suitable alternative to kerosene and hence can be safely used as fuels in cooking stoves.
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ADVANTAGES AND DISADVANTAGES OF BIOFUEL OR PROS AND CONS

The promise to reduce the carbon footprint in the next several decades necessitates a large-scale commercial use of renewable energies across the globe. An ambitious target for reducing greenhouse gas emissions promoted the use of biofuel mostly in the electricity sectors in countries like China, EU, Japan, and the Republic of Korea. The potential use of biofuel over traditional commercial fuels inside heavily polluted cities as well as in urban areas relies on its versatile fuel characteristic features. Biofuel is popular due to its renewability, non-toxicity, non-flammability, portability, easy-availability, biodegradability, sustainability, and eco-friendliness. It is free from sulfur and has very high oxygen content but no aromatic content and thus produces less smoke due to its soot-free nature [56]. This essentially leads to less polluting combustion [13, 56, 57, 58] unlike conventional diesel fuels. During burning, biodiesel produces less carbon dioxide on a life cycle basis and emits a very less amount of particulate matter in the atmosphere. Thus it also minimizes toxicity of air and reduces both cancer risks and neonatal defects significantly. Apart from these, biodiesel acts as a better lubricant in fuel pumps and various injector units and thus enhances engine efficiencies [57, 58]. Unlike commercially available petroleum diesels, Biodiesel has a higher flash point that not only offers safer storage but also facilitates the processes like the transportation, handling, distribution and utilization of biodiesel compared to for other conventional alternatives [13]. On the other hand, compared to petroleum diesel, biodiesel lacks the requirement for drilling, transportation and refining and thus provides opportunities to individual countries to produce biodiesel locally so that tariffs or similar taxes are waived for the countries that import oils or petroleum diesels. Thus production of biodiesel not only fosters rural development by recycling degraded lands but also promotes rural employment and economic gain [59].

Besides several advantages, biodiesel has a few disadvantages, too. Compared to petroleum diesel, biodiesel is less volatile due to a higher cloud point, a higher pour point and a higher viscosity that enhances the injector pressure [60] and undergoes incomplete combustion that causes deposit formation in engines [3,13,57, 58] that again leads to lower oxidation stability and corrosion of fuel tanks, pipes and injectors[49,60]. Moreover, due to lower energy content, biodiesel results in increased fuel consumption. Moreover, it causes corrosion in vehicle materials (copper and brass) such as fuel system blockages, seal failures, filter clogging and deposit formation at injection pumps due to higher NOx emission levels than other commercial diesel[49]. Since most biofuels are derived from edible oils, large production may lead to further socio-economic problems which may even cause a global imbalance in food supply-and-demand market [58]. A few other factors, such as less engine speed and power, high cost, high engine wear and engine incompatibility can also be considered as important drawbacks of the commercial use of biodiesel in the global market.

POLICY AND GOVERNMENT INCENTIVES

In the present century, a few countries like Indonesia, Malaysia, the Philippines and Thailand have taken important leads in the field of commercialization of biofuel in the ASEAN (Association of South East Asian Nations) countries. To foster the yield and commercial use of biofuel across the globe, suitable policies on the aims and objectives of biodiesel manufacture, blending mandates, tax incentives and other financial schemes have been adopted. Thus an overall enhancement of biofuel production along with an increasing trend of its commercial demand across the world market requires enforcing mandates, realizing supportive policy targets, ensuring security concerns and developing socio-economic status for the respective countries.

Several important policies related to the production, storage and trade of biofuels adopted so far, such as the National Biofuel Policy (Malaysia in 2006), The National Energy Policy (Indonesia, 2006), Alternative Energy Development Plans (AEDP) (Thailand), The Biofuels Act (Philippines, 2006) primarily aim to minimize the regular use of nonrenewable fossil fuels to discard harmful and greenhouse gas (GHG) emissions, encourage and promote the utilization of sustainable clean energy without any harmful hazards to the environment, promote biodiversity and thus rationalize energy cost by discarding unwanted subsidies to improve the energy-security of the country. In addition to these, several other issues like promoting the manufacture of biofuels utilizing the feedstock from agricultural production, creation of additional jobs in energy sectors to reduce poverty level in the country, rural electrification and encouraging research and development to expedite domestic renewable energy technology in international market are also taken into account while implementing these policies into action across the ASEAN countries.

Besides planning and implementing several policies, several incentives, taxes and levies have been introduced by the Government. Moreover, the Government also has granted huge money in the form of loans and federal grants at low interest to encourage research projects that facilitate the promotion of biofuels across the countries. Apart from these, income tax payable on investments and bio-energy sectors in specific regions has been reduced. This particular attempt encourages promoting and developing various biofuel feedstock plantations that helps to renew existing plantations to enhance the quality of the seedlings and emphasizes value-added production by enforcing some mandatory requirements of domestic biodiesel consumption. The sale of various raw materials commonly used for biodiesel production, such as coconut, jatropha, sugarcane, cassava, corn, and sweet sorghum has also been exempted from the value-added tax that also attempts to foster the practice of using biofuels across the countries.

CONCLUSION

The continuous depleting trend of non-renewable energy resources and consequent environmental hazards has motivated researchers to explore sustainable alternative fuels for the benefit of mankind. As a result, biodiesel commonly derived from renewable fat and oil resources has evolved as a very promising candidate that finds its applications in various fields like mining and marine situations where cleaner emission for lower pollution levels is highly solicited. This review attempts to present a brief description of the common resources and strategies for biodiesel production. The present and future applications of biodiesel as a promising sustainable fuel also have been discussed briefly in the present article. The pros and cons of the global commercial utilization of biodiesel along with the policies and the government incentives adopted to promote its production across the globe have also been incorporated. Overall the review attempts to highlight all the important potential aspects of biodiesel as one of the important sustainable energy fuels for the future world.

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REFERENCES

[1]. G. Knothe, JV Gerpen, J. Krahl, “The biodiesel handbook” *AOCS Press*, 2005

[2]. A. Demirbas, "Biofuels sources, biofuel policy, biofuel economy and global biofuel projections" *Energy Convers. Manage*. Vol. 49, 2106–16, 2008

[3]. AE. Atabani, AS Silitongac, IA Badruddin, T.M.I. Mahlia, H.H. Masjuki, S. Mekhilef "A comprehensive review on biodiesel as an alternative energy resource and its characteristics" *Renew Sustain Energy Rev*. Vol. 16, 2070–2093, 2012

[4]. NCO Tapanes, Donato A. Gomes Aranda, J W. de Mesquita Carneiro, O A. Ceva Antunes, "Transesterification of Jatropha Curcas oil glycerides: theoretical and experimental studies of biodiesel reaction", *Fuel* Vol. 87, 2286–2295, 2008

[5]. B Freedman, EH Pryde, TL Mounts, "Variables affecting the yields of fatty esters from transesterified vegetable oils" *JAOCS* Vol. 61, 1638–43, 1984

[6]. IM Atadashi, MK Aroua, AA Aziz, "High quality biodiesel and its diesel engine application: a review" *Renew Sustain Energy Rev* Vol. 14(7), 1999–2008, 2010

[7]. AS Ramadhas, S Jayaraj, C Muraleedharan, "Use of vegetable oils as I.C. Engine fuels – a review" *Renew Energy* Vol. 29, 727–42, 2004

[8]. M Kaltschmitt, AG Reinhardt, T Stelzer, "Life cycle analysis of biofuels under different environmental aspects" *Biomass Bioenergy* Vol. 12(2), 121–34, 1997

[9]. F Ma, MA Hanna, "Biodiesel production: a review" *Bioresour Technol*. Vol. 70, 1–15, 1999

[10]. M Balat, H Balat, "A critical review of biodiesel as a vehicular fuel" *Energ Convers Manage.* Vol. 49, 2727–2741, 2008

[11]. MS Friedrich, "A worlwide review of the commercial production of biodiesel – a technological, economic and ecological investigation based on case studies" *Department of Technology and Sustainable Product Management (ITNP), Wien,* August 2–6, 2004

[12]. A Dufey, " Biofuels production, trade and sustainable development: emerging issues. Environment Report" *London, UK: International Institute for Environment and Development (IIED),* 2006

[13]. EM Shahid, J Jamal, "Production of biodiesel: a technical review" *Renew Sustain Energy Rev*. Vol. 15(9), 4732– 4745, 2011

[14]. J Janaun, N Ellis, "Perspectives on biodiesel as a sustainable fuel" *Renew Sustain Energy Rev*. Vol. 14(4), 1312– 1320, 2010

[15]. D Bajpai, VK Tyagi, "Biodiesel: Source, Production, Composition Properties and its benefits" *J Oleo Sci*. Vol. 55 (10), 487–502, 2006

[16]. MM Gui, KT Lee, S Bhatia, "Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock" *Energy* Vol. 33(11), 1646–53, 2008

[17]. M Seenuvasan, PK Selvi, KM Anil, et al. "Standardization of non-edible Pongamiapinnata oil methyl ester, conversion using hydroxyl content and GC–MS analysis" *J Taiwan Inst.Chem Eng.* Vol. 45(4), 1485–1489, 2014

[18]. Q Li, W Du, D Liu, "Perspectives of microbial oils for biodiesel production" Appl. Microbiol. Biotechnol. Vol. 80, 749–756, 2008

[19]. F Ma, L D Clements, MA Hanna, "Biodiesel Fuel from Animal Fat. Ancillary Studies on Transesterification of Beef Tallow" *Ind. Eng. Chem. Res*. Vol. 37(9), 3768– 3771, 1998

[20]. K. Balakrishnan, M. A. Olutoye, B. H. Hameed, "Synthesis of methyl esters from waste cooking oil using construction waste material as solid base catalyst" *Bioresour. Technol*., Vol. 128, 788–791, 2013

[21]. M. Atapour, H. R. Kariminia , P. M. Moslehabadi, "Optimization of biodiesel production by alkali-catalyzed transesterification of used frying oil", *Process Saf. Environ. Prot*. Vol. 92, 179–185, 2014

[22]. R. Alarcón., D. M.Romero, A. Ladino, "Biodiesel production from waste frying oil and palm oil mixtures", *Chemical Engineering Transactions*, Vol. 57, 571–576, 2017

[23]. M. Raqeeb, R. Bhargavi, "Biodiesel production from Wsate cooking oil", *Journal of Chemical and Pharmaceutical Research*, Vol. 7 (12), 670-681, 2015

[24]. L Lin, Z Cunshan, S Vittayapadung, S Xiangqian, et al. "Opportunities and challenges for biodiesel fuel" *Appl Energy*. Vol. 88(4), 1020–1031, 2011

[25]. Jr CN Stewart, "Biofuels and biocontainment" *Nat Biotechnol* Vol. 25(3), 283–4, 2007

[26]. M Sticklen, "Plant genetic engineering to improve biomass characteristics for biofuels", *Curr.Opin. Biotechnol* Vol. 17(3), 315–9, 2006

[27]. W Du, W Li, T Sun, X Chen, D Liu, "Perspectives for biotechnological production of biodiesel and impacts" *Appl. Microbiol. Biotechnol* Vol. 79(3), 331–7, 2008

[28]. J Gressel, "Transgenics are imperative for biofuel crops" *Plant Sci* Vol. 174 (3), 246–63, 2008

[29]. MB Sticklen, "Plant genetic engineering for biofuel production: towards affordable cellulosic ethanol" *Nat Rev Genet* Vol. 9(6), 433–43, 2008

[30]. Md. Hizami, Md. Yusoff , Md Ayoub , Md. H Nazir , F Sher , I Zahid , M Ameen, "Solvent Extraction and performance analysis of residual palm oil for biodiesel production: Experimental and simultaneous study", *Journal of Environmental Chemical Engineering*, Vol. 9, Issue 4, 105519, 2021

[31]. C Casimir, Akoh, SW Chang, GC Lee, J Shaw, "Enzymatic Approach to Biodiesel Production", , *J. Agric. Food Chem.* Vol. 55, 22, 8995–9005, 2007

[32]. A.W Schwab, M.O Bagby, B Freedman, “Preparation and properties of diesel fuels from vegetable oils” *Fuel* Vol. 66, 1372-1378, 1987

[33]. N.O.V Sonntag, “Reactions of fats and fatty acids. Bailey's industrial oil and fat products” *4th edition, ed. Swern, D., John Wiley & Sons, New York*, vol. 1, 99, 1979

[34]. P.B Weisz, W.O Haag, P.G Rodeweld, “Catalytic production of high-grade fuel (gasoline) from biomass compounds by shaped elective catalysis” *Science* Vol. 206, 57-58, 1979

[35]. AW Schwab, GJ Dykstra, E Selke, et al. “Diesel fuel from thermal decomposition of soybean oil”, *JAOCS*. Vol. 65, 1781–1786, 1988

[36]. SN Gebremariam , J M Marchetti, “Biodiesel production technologies: review”, *AIMS Energy* , Vol. 5, Issue 3, 425-457, 2017

[37]. C.C Chang, S.W Wan, “China's motor fuels from tung oil”, *Ind. Eng. Chem* Vol. 39, 1543-1548, 1947

[38]. R.A Niehaus, C.E Goering, L.D Savage, Jr S.C Sorenson, “Cracked soybean oil as a fuel for a diesel engine” *Trans. ASAE* Vol. 29, 683-689, 1986

[39]. D Pioch, P Lozano, M.C Rasoanantoandro, J Graille, P Geneste, A Guida, “Biofuels from catalytic cracking of tropical vegetable oils” *Oleagineux* Vol. 48, 289-291, 1993

[40]. J Asomaning, P Mussone, D C. Bressler, “Pyrolysis of polyunsaturated fatty acids”, *Fuel Processing Technology*, Vol. 120, 89-95, 2014

[41]. B Rusdianasari, A Hasan, “Pyrolysis Process of Fatty Acid Methyl Ester (FAME) Conversion into Biodiesel”, *International Journal of Research in Vocational Studies (IJRVOCAS)*, Vol.1, No.2, 2021

[42]. YC Sharma, B Singh, SN Upadhyay. “Advancements in development and characterization of biodiesel: a review” *Fuel*. Vol. 87(12), 2355–2373, 2008

[43]. SP Singh, D Singh. “Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review” *Renew Sustain Energy Rev*. Vol. 14(1), 200–216, 2010

[44]. H Fukuda, A Konda, N Noda. “Biodiesel fuel production by transestirification of oils” *J BiosciBioeng.* Vol. 92, 405–416, 2001

[45]. S Soltani, U Rashid, R Yunus, et al. “Synthesis of Biodiesel through Catalytic Transesterification of Various Feedstocks using Fast Solvothermal Technology: ACritical Review” *Catal Rev Sci Eng*. 407-435, 2015

[46]. Y Chisti. “Biodiesel from microalgae” *Biotechnol Adv*. Vol. 25(3), 294–306, 2007

[47]. LC Meher, D VidyaSagar, SN Naik. “Technical aspects of biodiesel production by transesterification – a review” *Renew Sustain Energy Rev*. Vol. 10(3), 248–268, 2006

[48]. MA Xiao, S Mathew, JP Obbard. “Biodiesel fuel production via transesterification of oils using lipase biocatalyst”. *Gcb Bioenergy*. Vol. 1(2), 115–25, 2009

[49]. A Murugesan, C Umarani, TR Chinnusamy, et al. “Production and analysis of biodiesel from non-edible oils – a review” *Renew Sustain Energy Rev*. Vol. 13(4), 825–834, 2009

[50]. P Kumar Gupta, “Fate, Transport, and Bioremediation of Biodiesel and Blended Biodiesel in Subsurface Environment: A Review” *Journal of Environmental Engineering* Vol. 146(1), 03119001, 2020

[51]. S Das, A Chowdhury, “An exploration of biodiesel for application in aviation and automobile sector” *Energy Nexus*, Vol. 10, 100204, 2023

[52]. T Hassan, Md. M Rahman, Md. A Rahman, Md N Nabi, “Opportunities and challenges for the application of biodiesel as automotive fuel in the 21st century”, *Biofuels, Bioproducts and Biorefining (Biofpr)*, Vol. 16,issue 5, 1353-1387, 2022

[53]. G Wu, J. C Ge, N. J. Choi, “A Comprehensive Review of the Application Characteristics of Biodiesel Blends in Diesel Engines” *Applied Sciences* Vol. 10(22), 8015, 2020

[54]. A Elfasakhany, “Biofuels in Automobiles: Advantages and Disadvantages: A Review” *Current Alternative Energy*, Vol. 3, 1-7, 2019

[55]. J C Ge, S. K Yoon, M S Kim, N J Choi, “Application of Canola Oil Biodiesel/Diesel Blends in a Common Rail Diesel Engine”. *Applied Sciences*, Vol. 7(1), 34, 2017

[56]. SP Chincholkar, S Srivastava, A Rehman, et al. “Biodiesel as an alternative fuel for pollution control in diesel engine” *Asian J Exp Sci*. Vol. 19 (2), 13–22, 2005

[57]. M Balat, H Balat. “Progress in biodiesel processing” *Appl Energy*. Vol. 87(6), 1815–1835, 2010

[58]. N Yusuf, SK Kamarudin, Z Yaakub. “Overview onthe current trends in biodiesel production” *Energy Convers Manage*. Vol. 52(7), 2741–2751, 2011

[59]. G Knothe. “Biodiesel and renewable diesel: a comparison” *Prog Energy Combust Sci*. Vol. 36(3), 364–373, 2010

[60]. S Li, Y Wang, S Dong, et al. “Biodiesel production from Eruca Sativa Gars vegetable oil and motor: emissions properties”. *Renew Energy*. Vol. 34(7), 1871–1876, 2009