International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-10, Jan 2024

Comprehensive Review of Biodiesel: A Holistic Exploration of Production, Application, and Environmental Impacts

#Aryan Verma, Student, Department of Biotechnology, RR Institute of Modern Technology (AKTU), Lucknow, Uttar Pradesh, India, Aryanver34@gmail.com

#Nishchal Maurya, Student, Department of Biotechnology, RR Institute of Modern Technology (AKTU), Lucknow, Uttar Pradesh, India, nishchalmaurya0987@gmail.com

***Dr. Yashdeep Srivastava, Assistant Professor, Department of Biotechnology, RR Institute of Modern Technology (AKTU), Lucknow, Uttar Pradesh, India, yashbubiotech@gmail.com**

Dr. Dheerendra kumar, Assistant Professor, Department of Biotechnology, RR Institute of Modern Technology (AKTU), Lucknow, Uttar Pradesh, India, dkbriindia@gmail.com.

***Corresponding Author: Dr. Yashdeep Srivastava (yashbubiotech@gmail.com)**

#Both Authors contributed equally

Abstract - Since the supplies of fossil fuels in developing countries are predicted to run out in 65 years, biodiesel produced by transesterification presents a viable substitute. Issues like residual components and strict regulations bring about obstacles. Biodiesel is examined in the abstract as a potential alternative with its own set of technical and quality considerations, and it highlights the urgency of moving away from fossil fuels. While state and federal governments are encouraging the rapid development of biodiesel, the fuel currently depends on subsidies to remain competitive. The creation of markets for more fats, the reduction of dependency on imported fossil fuels, the reduction of carbon emissions and exhaust pollutants, and the enhancement of fuel qualities are the five main factors for the growth of biodiesel. While diesel made from petroleum cannot completely replace biodiesel, it does provide a more environmentally friendly and sustainable option. The availability of feedstock, economic viability, and continuous technology developments are some elements that affect the environmental benefits and the potential for production scaling. The biodiesel business is working to make biodiesel a more sustainable and cleaner substitute for traditional diesel fuels.

Keywords- Alternative energy, Biodiesel, Biofuel, Bio-resource, Bio-energy, Transesterification,

I. INTRODUCTION

Fuels are very important because they can generate a lot of energy when they burn. The world's energy consumption is 80% derived from fossil fuels such as coal, oil, and natural gas resources [1]. Due to this circumstance, fossil fuels are now heavily relied upon in daily life. The significant economic growth in some developing nations will result in the depletion of fossil fuel resources in a mere 65 years [2].

Furthermore, air pollution and global warming are exacerbated by emissions from the process of fossil fuel combustion. For most countries, international pressure on global warming issues is also growing [3]. A catalyst and an alcohol, usually methanol, are used to transesterify the parent oil or fat in order to produce biodiesel such as alkoxides or sodium or potassium hydroxide—is present [4]. The desired alkyl ester product, residual alcohol, residual catalyst, and unreacted starting material (TAG) may all be present in the final product [5]. Traces of glycerol can still be found in the finished product even though It is created during the production process as a byproduct and purified from biodiesel [6]. Biodiesel standards address things like analysis, fuel quality, as well as manufacturing monitoring. Additional difficulties include the oxidation linoleic and linolenic acid susceptibility, among different other esters, handling and keeping concerns, and the physical and fuel characteristics [7]. Even though Petro diesel standards include some requirements for biodiesel standards, not all testing techniques are suitable for assessing biodiesel.

 DOI : 10.35291/2454-9150.2024.0005

II. DEFINITION OF BIODIESEL

Grease, vegetable or animal fats can be used to make biodiesel, a fuel that burns cleanly. Either the esterification of fatty acids or their transesterification of oily substances with short-chain alcohols yields it. Triglycerides undergo transformation into alkyl ester forms of fatty acids during the process, which yields glycerol as a byproduct. Alcohols like methanol or ethanol are additionally involved, as is a catalyst that acts like a neutralizer or acids. The appeal of biodiesel as an environmentally friendly and renewable fuel has grown as a result of the depletion of petroleum reserves and the damaging effects of petroleum diesel exhaust fumes on the environment [8]. Renewably and biodegradably derived, biodiesel contains solely of fats compared to plants or animals. Transesterification with methanol, which is triggered by an alkali and has a fast reaction time, is presently the most used technique for producing biodiesel [9]. But since water, free fatty acids, or both can increase the amount of soap produced, both alcohol and plant-based oil must be predominantly anhydrous and low in free fatty acids. Standard diesel cars can run upon biodiesel-based gasoline without changing their combustion engines; older cars may need to have rubber parts changed, which includes their fuel lines. Since it burns more completely and extends engine life compared to diesel fuel, biodiesel is an improved lubricant due to its oxygenation [10]. To improve low-sulfur diesel fuel's lubricity, several nations are introducing blends of biodiesel.

This study examines the effects of algae culture on diesel engines critically and draws attention to the discrepancies between the literature on biodiesel production, oil extraction, and algae culture as it relates to diesel engine performance [11]. Findings indicate that torque and power output have decreased, with B20 being the blend that is most similar to diesel fuel. Emulsions present a promising substitute with lower emissions of NOx and CO_2 [12] Nonetheless, dearths of engine tests reveal inconsistent outcomes or poorly researched behaviours, emphasising the necessity for additional research in this area. It will take the resolution of several technical challenges earlier than biodiesel turns into a profitable option. Firstly, the triglycerides are derived from virgin plant-based oil, which is costly and has a significant impact on the process's economic viability [13, 14]. It might grow to be competitive with diesel produced from petroleum by using less costly raw materials as raw materials, such as animal fats, used frying oils, and non-edible oils, to reduce production costs. However, the relatively greater concentrations of water and the feedstock's free fatty acids lead to the process of making soap with alkali catalysts present requiring further processes to remove any remaining water and either the soap or the free fatty acids from the combination [15]. . Studies have been conducted on biodiesel produced with alkali catalysts from virgin oils made from vegetables, like rapeseed, sunflower, and soybean. Alkali-catalyzed transesterification with methanol is the method most commonly used today to produce biodiesel because of its quick reaction time [16, 17]. Utilising biotechnology approaches, biodiesel made from soybean oil could have its composition transformed in order to improve production and application productivity.

III. BIODIESEL AS AN ALTERNATIVE ENERGY SOURCE

Biodiesel provides environmental sustainability as it has a lower carbon footprint than conventional fuels derived from petroleum [18]. Biodiesel is derived from replenishable resources like cellulosic biomass, animal fats, used vegetable oils(UVO), algae, Jatropha, municipal solid waste, waste glycerol, and genetically modified crops. They have become indispensable to the carbon footprint reduction while they're boast a closed carbon cycle, where the carbon released during combustion is initially absorbed by the plants during their growth. This results in a significant reduction in overall carbon emissions, making biodiesel an important participant in battling climate change [19]. During the combustion of biodiesel, it lowers the emission of sulfur and other particulate matter compared to traditional diesel, which at last helps in improving the air quality and also in mitigating the respiratory diseases and other health issues associated with air pollution, especially in urban areas.

Furthermore, biodiesel is crucial for maintaining energy security and minimizing reliance on fossil fuels because It originated from several fuel sources. By releasing energy original sources, fuel costs are stabilized and become less vulnerable to geopolitical unrest or breakdowns in the worldwide oil market [20]. Additionally, the manufacturing of biodiesel helps rural development by generating wages in the biofuel and agricultural sectors, which supports the economy and the fight against poverty.

In addition, biodiesel has a longer lifespan, won't break down as easily, and can be preserved for a longer period of time. It can also serve as a backup during a failure or shortage of primary energy supply. Integrated biorefinaries are also showing interest in gaining traction in biodiesel production [21]. This concept, in addition, utilizes not only the main product, which is biodiesel, but also converts biomass into value-added products, including biochemicals and other biomaterials, which overall helps in waste reduction (Fig.1) Apart from being a fuel, biodiesel can also be a viable solution that can integrate environmental sustainability, social well-being, and economic stability [22].

IV. PRODUCTION PROCESS OF BIODIESEL

The emissions associated with diesel fuel derived from petroleum could be considerably lessened with the use of biodiesel, a renewable fuel. Although biodiesel currently needs subsidies to directly compete with fuels derived from petroleum, both the federal and state governments are offering incentives to promote its quick development.

 DOI : 10.35291/2454-9150.2024.0005

Although the country uses about 33 Millions of dollars tonnes of on-highway fuel made from diesel annually, the United States of America generates sufficient plant-based oil and animal fat to make a total of 4.6 billion tonnes of biodiesel every year [23]. If every last drop of oil from plants and animal fat generated in the USA could be used to make biodiesel, it would only replace 14% of the present necessity for on-highway gasoline made from diesel. Diesel fuel generated from petroleum can be swapped out for biodiesel because of its renewable nature and closed carbon cycle. It further decreases the release of carbon dioxide altogether [24].

Biodiesel is renewable and doesn't cause global warming, closed cycle of carbon. A biodiesel life cycle analysis revealed that generally When compared to diesel derived from petroleum, CO_2 emissions were 78% lower energy source [25,26]. Carbon monoxide, unburned hydrocarbons, and other exhaust emissions Biodiesel produces fewer particulates into the air than conventional diesel fuel. The majority of emissions tests, regrettably, have demonstrated a little increase in nitrogen oxides, or NOx [27]. If added to conventional diesel fuel in a concentration of 1-2 percentage points it may render fuel with poor hydraulic qualities—like today's ultra-low-sulfur gasoline fuel—acceptable [28]. The first kind of fuel called biodiesel is generated by converting to the original oil or fat by employing methanol, an alcohol, while a catalyst, which is something like alkoxides or either potassium or sodium hydroxide, is provide [29]. Remaining alcohol, residual catalyst, and unreacted starting material (TAG) may be present in the final product. Traces of glycerol can still be found in the finished biodiesel product even enough during the manufacturing process it differentiates from biodiesel and creates as a by-product [30]. Biodiesel also contains MAG and DAG that are produced as intermediates [31]. Standards for biodiesel cover topics like the investigation, quality of fuel, and production surveillance. Nevertheless, not all standards-related factors have been taken into account, particularly in light of their recent adoption, which has resulted in new categories and developments for biodiesel standards.

The making of biodiesel, which is made from spent cooking oil, animal fats, and plant-based oils, is a more sustainable and environmentally friendly choice compared to diesel fuel created via petroleum. Transesterification is the process of converting triglycerides into biodiesel and glycerol. This process reduces reliance on fossil fuels, lowers greenhouse gas emissions, and promotes renewable energy sources manufactured in the United States. Pretreatment of feedstock, transesterification, separation and washing, drying, and optional additive addition are all critical steps in the production of biodiesel. The role of catalysts is significant in the chemical reactions which convert triglycerides into biodiesel and glycerol [32]. Depending on factors such as economic viability, feedstock availability, and environmental concerns, biodiesel production can be scaled up or scaled down. The industry strives to improve as technology and research in biodiesel production advance (Fig 2.).

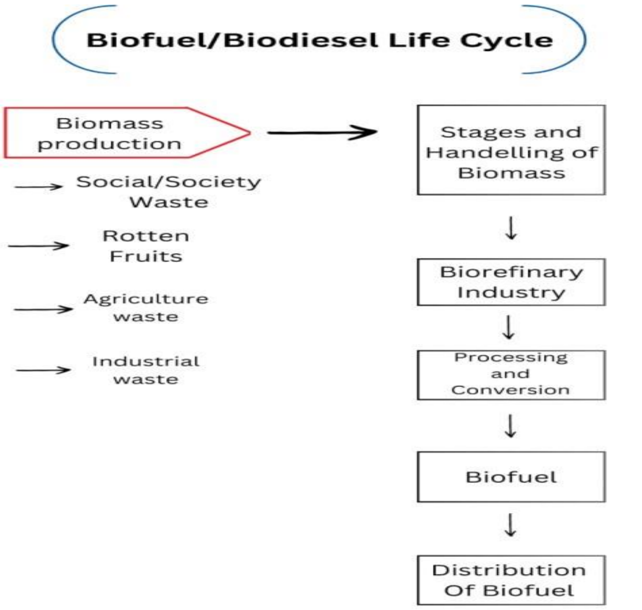

Figure 1. Biodiesel manufacturing process. The cycle starts with feedstock, which consists of basic ingredients like animal or vegetable fats. These feedstock's are then converted into biodiesel by a chemical process known as transesterification. The figure expertly illustrates the process of purifying biodiesel and the separation of glycerine as a by product. Subsequently, a detailed presentation of the supply chain and distribution phases follows, highlighting the different means of transportation and the storage facilities. To underscore a viable and efficient route from production to consumer access, the last segment depicts biodiesel's seamless entry into the market.

V. FEEDSTOCK SELECTION

Overcoming technological advances presents challenges, such as the high price of using virgin plant-based oil as a fatty acid source, which must be overcome for biodiesel to be successful [33]. Low-cost feedstocks can be used as raw materials to cut production costs and exceed petroleum-based diesel, such as animal fats, waste frying oils, and nonedible oils. But if a catalyst made from alkali is present, the greater quantity of water and the feedstock contains fatty acids can lead to the production of soap. Water and free fatty compounds must be eliminated from the combination by taking further processes [34].

A promising feedstock for biodiesel, high iodine content is seen in soybean oil and is stable in stable fuel and less unstable in unstable fuel. However, adding seawater to the fuel storage tanks on US Navy aircraft carriers can result in problems with fuel instabilities, which includes engine failure and filter interruption. When using recycled oil, record fatty acids that are in the oil and water from the sea may produce a soapy water. The cultivation of rapeseed oil is a simple and efficient method for producing methyl

 DOI : 10.35291/2454-9150.2024.0005

esters that does not pollute the environment or waste water. Pyrolysis occurs in a tubular reactor in nitrogen and at temperatures between 500 and 850 degrees Celsius. The conversion of methyl colzate is facilitated by the temperature at which pyrolysis occurs. The principal byproducts are unsaturated fats methyl esters, n-parans, and expressed 1-oleones [35]. Light hydrocarbon yields increase with temperature. However, any environmental advantages of using oxygenated fuel are eliminated by the high cost of the thermal cracking and pyrolysis machinery for low throughputs, which also removes oxygen during thermal processing. As a result, some low-cost supplies and infrequently more gasoline than diesel fuel are produced [36]. The choice of a raw material, which is different in composition, triglyceride content, and properties, is crucial to the production of biodiesel. Common feedstocks include plant-based oils including sunflower, canola, and soy oil; animal fats like tallow and chicken fat; utilised cooking oil (UCO); algae-derived oil; and the jatropha plant oil [37]. Because of their availability and favourable transesterification properties, The oils of vegetables are widely used, which includes oil from soybeans because of its cold flow properties and low saturated fat levels, canola oil is a popular feedstock. Sunflower oil is used as an alternative feedstock in areas where sunflower cultivation is prevalent. Biodiesel can also be created with fats from animals like a substance called and chicken fat [38].

VI. CRITERIA FOR SELECTION OF FEEDSTOCKS

Availability: The feedstock should be easily accessible in the region where biodiesel production is taking place.

Cost: The entire economics of producing biodiesel are influenced by the material cost. Certain feedstocks might be less expensive than others.

Climate and Soil Conditions: Certain crops or feedstocks may be better suited to certain climatic and soil conditions.

Sustainability: There is a growing emphasis on using feedstocks that have little impact on food production and ecosystems. Waste and byproduct feedstocks, such as UCO and animal fats, are considered more sustainable.

Regulatory Compliance: Regulations and standards associated with the specific type of material used in the production of biodiesel may vary among geographical areas.

The decision to use of feedstock is frequently a compromise between economic viability and environmental sustainability.

VII. TRANSESTERIFICATION

The chemical process known as transesterification creates monoesters when triglycerides and alcohol are combined with a catalyst (Fig 2.). The lengthy, branching-chain molecules of triglycerides are converted to glycerol and monoesters. [39]. Three consecutive reversible processes that make up the transesterification process are the transformation of triglycerides into diglycerides and then back again into monoglycerides. The glycerides are converted into glycerol and one ester molecule is produced in each phase [40]. Both with and without a catalyst, the transesterification process is carried out. The catalyst is used to quicken the process and create higher-quality biodiesel. Enzyme, acid, and alkaline catalysts have all been employed, based on the properties of the feedstock [41]. Every catalyst has benefits and drawbacks when used. Alkaline catalysts are superior than acid catalysts because of their lower reaction temperature, quicker reaction (shorter reaction time), and higher conversion efficiency.

The synthesis of biodiesel now uses homogenous alkaline catalysts because an acid catalyst's transesterification reaction proceeds much more slowly than a base-catalyzed process [42]. Numerous in-depth studies have been conducted on base-catalyzed transesterification. The most commonly used basic catalysts are potassium hydroxide (KOH),sodium ethoxide ($NaOCH_2CH_3$), sodium methoxide ($NaOCH_3$), and sodium hydroxide (NaOH) [43]. The two-stage process of waste oil transesterification employing stoichiometric ratios of KOH and methanol, supplemented with KOH in precisely the proper amounts to balance acidity. Both reactions took place between 40 and 60 °C for 30 minutes to finish. The two-step, alkaline-catalyzed transesterification reaction was shown to be an affordable way to turn used vegetable oil into biodiesel [44].

The method is referred to as methanolysis if methanol is utilized. Methanol is used in the chemical process of methanolysis to change or decompose numerous molecules. Depending on the particular reaction and the composition of the starting ingredients, different methanolysis routes exist. In this comprehensive review, we will look at the mechanisms of ester methanolysis in organic chemistry, cellulose methanolysis in biomass conversion, and methanolysis in the context of transesterification [45]. Triglycerides, which frequently appear in vegetable oils or animal fats, undergo transformation into glycerol and fatty acid methyl esters (FAME) during the vital phase of transesterification, which is the process of producing biodiesel.The alcohol component of this reaction is methanol, and the process is aided by a catalyst, usually potassium or sodium hydroxide.

 DOI : 10.35291/2454-9150.2024.0005

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-10, Jan 2024

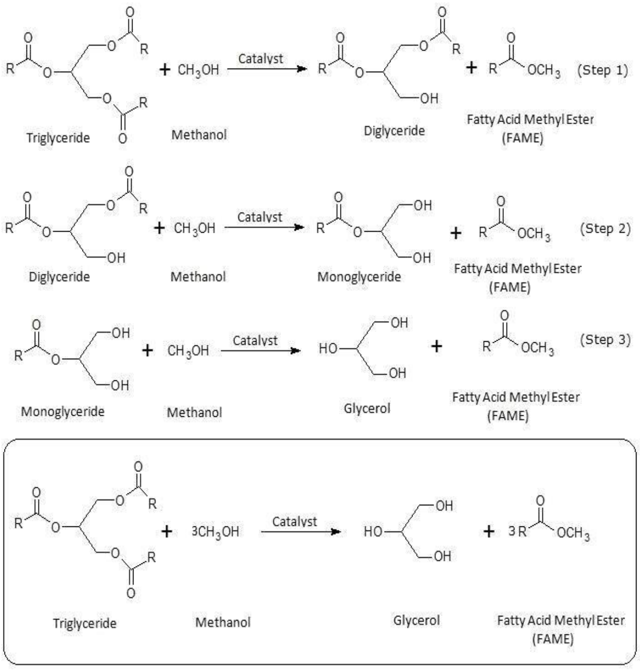

Fig 2. Transesterification reaction for production of biodiesel

It is essential to comprehend transesterification kinetics in order to improve yield and reaction conditions. Reaction rates are largely dependent on variables including temperature, pressure, and reactant concentrations. As a way to help in the design of enhanced biodiesel production systems, researchers are looking into kinetic models for estimating reaction behaviour under various conditions.

Although the primary emphasis of classical transesterification is on triglycerides derived from animal fats or vegetable oils, current research is broadening the scope to encompass a variety of feedstocks [46]. Alternative sources for producing biodiesel are emerging, including algae, leftover cooking oil, and even microorganisms that have been modified genetically to make fatty acids. For the production of sustainable biodiesel, adapting transesterification conditions to these numerous feedstocks poses both opportunities and challenges.

Transesterification is usually carried out in batch reactors. But considering their possible benefits, continuous flow systems are becoming progressively more common. Better scalability, shorter reaction times, and greater oversight over reaction parameters are all provided by continuous processes. The manufacturing of biodiesel could become more efficient and profitable with the use of continuous flow technologies. Researchers are investigating ways to make transesterification more environmentally friendly in compliance with the core ideas of green chemistry [47]. This includes trading out conventional organic solvents with eco-friendly ones like ionic liquids or supercritical fluids. Furthermore, initiatives are in place to reduce energy usage and waste production during the transesterification process. Co-solvents are being studied as potential transesterification additives for improving reactant solubility and mass transfer rates. Co-solvents with the potential to improve reactant mixing and boost the production of biodiesel include ethanol and dimethyl carbonate. Research on the ideal co-solvent conditions is currently being carried out in the field of biodiesel synthesis. Transesterification efficiency may be hampered by product inhibition, specifically glycerol production[48]. Strategies for in-situ product removal, like the use of adsorbents or membrane reactors, are intended to lessen this problem. In an attempt tochange the equilibrium in favor of more biodiesel production, researchers continually remove one or more products from the process.

VIII. ENVIRONMENTAL IMPACT OF BIODIESEL

Because of its environmental benefits and renewable resources, biodiesel, a renewable fuel, has grown in popularity. However, the high cost remains a significant barrier to commercialization. Utilizing used cooking oil, continuing the process of transesterification, or extracting premium glycerol from biodiesel byproducts are ways to reduce the cost of production. Biodiesel comes into existence through four primary processes: direct use and amalgamation, microemulsions, thermal breakdown (pyrolysis), and transesterification. The procedure that is most often employed, the vegetable and animal fats are transesterified, hinges on a number of variables, including catalysts, temperatures, duration, free fatty acids, and the glyceride to alcohol ratio [49]. Biodiesel glycerol, a renewable resource, has gained popularity due to its environmental benefits and the the accessibility of fats and oils supplies. However, The price and scarcity of these assets pose challenges. The cost of the essential components accounts for between 60 and 75 percent of the total cost of biodiesel fuel [50]. The cost can be greatly reduced by using old cooking oil, but the quality may suffer. Research is required to determine a less expensive method of producing biodiesel fuel from used cooking oil.

Production cost can be reduced through continuous transesterification processes & recovery of by-products (glycerol). Because of its higher yield and faster reaction time, a continuous transesterification technique is a preferred option [51]. If a biodiesel plant contains a facility for recovering glycerol on site, the process of recovering top-notch glycerol from biodiesel glycerol is less complicated than with typical soap glycerol recovery. Furthermore, the cost of biodiesel gasoline can be reduced. The proposed increasing worldwide population of humans may require more territory for food production, which could lead to higher vegetable oil prices. Rather than being the only source of energy, biodiesel can be utilized in conjunction with other sources. It is especially helpful in mining and maritime environments where it is crucial to have lower pollution levels. The biodiesel can reduce the US's reliance on fuel imported from petroleum.

 DOI : 10.35291/2454-9150.2024.0005

Biodiesel production has a significant environmental impact as a more sustainable substitute for conventional energy sources. It may be able to reduce greenhouse gas emissions, improve air quality, additionally decrease the use of hazardous pollutants [52]. The environmental impact of the manufacturing of biodiesel, however, is dependent on factors such as feedstock source, production methods, and land-use changes. Sustainable feedstock sourcing is critical to avoiding negative consequences such as deforestation, habitat destruction, and crop displacement [53]. Energy inputs are required for cultivation, harvesting, processing, and transportation during the biodiesel production process. The overall environmental benefit is determined by the equilibrium of energy, which is the proportion of energy produced to vitality consumed during the manufacturing process. Water-intensive processes may be used in the production of biodiesel, and effluent from biodiesel production may contribute to water pollution [54,55].

IX. RENEWABLE RESOURCES USE FOR PRODUCTION OF BIODIESEL

The primary ingredient of biodiesel, a cleaner and ecologically sound alternative of traditional diesel, includes a variety of environmentally friendly resources. The most common feedstocks used for manufacturing biodiesel are plant-based oils, spent oil to use for cooking and the fats from animals. Assessing their long-term viability and ecological impact of biodiesel requires an understanding of how these renewable resources are used in its production [56].

The production of biodiesel through the use of renewable resources coincides with the overarching goals of sustainability, energy security, and safeguarding the environment. Through recycling waste materials, utilizing non-food crops, and developing cutting-edge feedstock alternatives like algae, the biodiesel sector aims to reduce its environmental effect and diversify its source of resources.

1. Vegetable Oils:

One of the most prominent and extensively utilized feedstocks for the extraction and production of biodiesel is vegetable oil. Triglycerides that are present in oils extracted from crops like soybean, canola, sunflower, palm, and rapeseed can be transesterified to produce biodiesel. The production of these oilseed crops provides a renewable source of feedstock, and the oils can be gained through mechanical or chemical processes [57].

A. Soybean Oil: A vital feedstock for the creation of biodiesel, soybean oil makes a significant contribution to the worldwide biodiesel market. Many areas harvest soybeans, and the oil extraction process produces a feedstock rich in triglycerides that can be used in transesterification.

Challenges related to sustainability: Although soybean oil is readily accessible, its production has raised challenges like destruction of habitat and deforestation. Reducing the adverse impacts on the environment requires the implementation of sustainable practices, such as cautious land use and a strict adherence to certification requirements [58].

B. Canola Oil: Another widely used feedstock is canola oil, which is made from rapeseed. Canola plants are well-known for their capacity to adapt to a variety of climates, and the oil that is collected from the seeds is a vital resource for the manufacturing of biodiesel [59].

Environmental Benefits: Compared with regular diesel, canola cultivation for the production of biodiesel has fewer greenhouse gas emissions. The crop's sustainability profile is further enhanced by its capacity to mitigate erosion and support soil health [60].

C. Coconut oil: Even though coconut oil is a popular fruits and vegetables oil, issues with deforestation and biodiversity loss have been pointed up by its production. In order to solve these issues, sustainable practices and certification programs place a focus on ethical palm oil production for biodiesel [61].

Sustainability Initiatives: The push for of socially and environmentally responsible palm oil production has been significantly assisted by The Committee for Sustainable Palm Oil Production .

2. Animal Fats:

A potential feedstock for biodiesel is animal fats, a byproduct of the meat processing industries. These fats can be transesterified to yield biodiesel and have triglycerides resembling those found in vegetable oils. The circular economy is supported by the utilisation of animal fats in the production of biodiesel due to their ability to recover recyclable materials [62].

A. Tallow: Tallow is a typical biodiesel feedstock that originates from rendered animal fat. It is derived from several animal sources and offers an extra supply of triglycerides for the synthesis of biodiesel.

Waste Valorization: By optimizing the use of existing resources while decreasing the waste disposal difficulties faced by the meat industry, the use of animal fats for biodiesel production helps to promote a more sustainable and circular approach to industrial processes. A viable way to lessen environmental effect and encourage an environmentally friendly future is by promoting the manufacturing of biodiesel [63].

B. Yellow Grease: Another type of animal fat utilized in the manufacturing of biodiesel is yellow grease, which is frequently obtained from used cooking oils. Reusing leftover cooking oil solves disposal issues and is consistent with sustainable practices.

 DOI : 10.35291/2454-9150.2024.0005

C. Localized Solutions: The production of biodiesel from yellow grease is frequently a locally driven endeavor, including the cooperation of biodiesel producers and area rendering facilities to establish closed-loop systems that bolster local economies.

3. Wasted Cooking Oils: Recycling wasted cooking oils from homes and restaurants is a greener way to offer feedstock for biodiesel. Used cooking oils, often referred to as waste oils, contain triglycerides that can be transesterified to produce biodiesel.

A. Recycling and Repurposing: Gathering and recycling used cooking oils not only keeps them out of the environment but also turns them into a useful resource for the manufacture of biodiesel. By using this method, the carbon footprint of disposing of waste oil is minimised [64].

B. Community Participation: To gather leftover cooking oil, several biodiesel manufacturers work with nearby companies and organizations. In addition to increasing feedstock supply, this involvement raises community understanding of sustainable practices. Cleanliness aspects: For the manufacturing of biodiesel, it is essential to guarantee the quality of the feedstock, spent cooking oil. In order to guarantee that the finished biodiesel product satisfies industry standards, sufficient filtration and purification procedures are used to eliminate contaminants.

4. Algae as an Emerging Feedstock:

Utilising green algae as a bio diesel origin is a new frontier in the use of renewable resources. Algae are very effective in converting carbon dioxide and sunlight into lipids, or oils, which can then be collected and processed to make biodiesel. High oil yields and having the ability to grow on non-arable soil, resulting in lower competition with food crops, are two benefits of algae production.

A. High Oil Content: Algae can contain a lot more oil than conventional oilseed crops, thereby rendering them a desirable feedstock for the manufacturing of biodiesel. In recognition of their high lipid content, some species of algae are grown especially for this purpose.

Genetic Modification: In order to enhance lipid production, genetic alterations are being examined in algal bioengineering research [65]. Through genetic modification of algae species, researchers hope to increase oil output and increase efficiency. This could potentially lead to a significant breakthrough in renewable energy production.

B. Minimal Impact on Land Use: Algae cultivation can be carried out in ponds, bioreactors, or even plants that treat wastewater. This adaptability cuts out land use issues related to traditional feedstocks and relieves the strain on arable land.

Wastewater Treatment Integration: By treating wastewater and generating biomass for biodiesel, algae farming offers a two-fold advantage to wastewater treatment plants. This integrated strategy is consistent with the idea that one could generate valuable resources from waste streams.

5. Jatropha as a Non-Food Crop:

The non-food oilseed crop known as Jatropha curcas has drawn curiosity as a possible biodiesel feedstock. Because of their toughness, jatropha plants can grow well in marginal or dry regions where food crops might not do well. The Jatropha plant's seeds contain oil that can be used to make biodiesel.

A. Adaptability: Jatropha is a promising option for producing biodiesel without competing with food crops on important agricultural land because of its ability to adapt to a variety of climates and soil conditions.

Utilization of Marginal Lands: Planting Jatropha on areas unsuitable for food crops reduces the likelihood of conflicts arising from land use. This methodology is consistent with sustainable land management techniques, mitigating the ecological consequences linked to feedstock farming.

B. Research Focus and Obstacles: Although Jatropha exhibits potential, there are still obstacles to overcome, including protracted gestation times and problems with seed toxicity. The goal of ongoing research is to improve Jatropha's agronomic traits for more efficient production of biodiesel.

6. Microbial Oil from Oleaginous Microorganisms:

Beyond traditional vegetable oils and animal fats, oleaginous microorganisms—like certain fungi and microalgae—are attracting interest as potential feedstocks for the manufacturing of biodiesel. These microbes may produce large amounts of lipids, also known as microbial oil, which can be isolated and processed via transesterification to produce biodiesel.

A. Microalgae: These minuscule photosynthetic organisms can survive in a variety of settings, such as bioreactors, ponds, and even wastewater treatment plants. They have the ability to produce high lipid content and grow quickly, which are two benefits for biodiesel generation [66].

Heterotrophic and Phototrophic Cultivation: Heterotrophic microalgae are grown by feeding on organic molecules whereas phototrophic microalgae use sunlight for photosynthesis. With regard to its adaptability, manufacturing procedures can be customized according to particular environmental and financial considerations.

Biorefinery Concepts: Microalgae cultivation is frequently incorporated in biorefinery concepts, which extract and use the different components of the microalgae to maximize the value of the biomass. Examples of these components include lipids for biodiesel, proteins for animal feed, and carbohydrates for bioethanol.

B. Yeast and Fungi*:* The capacity to collect lipids is also known to exist in certain strains of these organisms. These

 DOI : 10.35291/2454-9150.2024.0005

microorganisms offer more opportunities for the sustainable production of biodiesel since they can be grown on a variety of substrates, such as industrial wastes and agricultural residues.

Metabolic Engineering*:* Researchers use metabolic engineering to improve microorganisms' capacity to produce lipids. This entails altering the organisms' genetic composition to maximize the processes that lead to lipid accumulation, hence raising the yields of biodiesel.

7. Waste Biomass and Residues:

Apart from specific crops and microorganisms, waste biomass and scraps emanating from other sources can function as feedstocks for the manufacture of biodiesel. This strategy is consistent with waste valorization and the circular economy.

A. Agricultural Residues*:* You can use rice husks, corn stover, and wheat straw—among other agricultural residues—as feedstocks for biodiesel. These residues frequently contain lignocellulosic components, which can be fermented to create lipids after being transformed into sugars. Biodiesel made from agricultural leftovers is regarded as a type of biofuel that belongs to the second generation. By using agricultural residues, items that would otherwise be thrown away or allowed to decay are put to better use and competition with food crops is reduced [67]. Biodiesel made from agricultural leftovers is regarded as a type of biofuel that belongs to the second generation. Through the consumption of agricultural residues, commodities that would otherwise be thrown away or allowed to deteriorate are put to better use and competition with food crops is reduced

B. Municipal Solid debris*:* It is possible to produce biodiesel from the organic parts of municipal solid trash, such as food waste and organic sludge. This technology offers an environmentally sustainable substitute for conventional garbage disposal techniques while also helping to reduce waste.

Anaerobic Digestion: In certain circumstances, the manufacture of biodiesel from municipal solid waste demands the creation of biogas through anaerobic digestion, which is then followed by the extraction of lipids from the residual organic material. The energy recovery from waste is maximized by this integrated strategy [68].

8. Hybrid Feedstock Approaches: Researchers are looking into hybrid feedstock approaches that will enhance the sustainability and financial viability of biodiesel production. They combine many feedstocks in order to maximize resource usage and get beyond the drawbacks associated with employing only one source.

A. Crop Residue Integration: A hybrid feedstock system can be produced by combining typical oilseed crops with their residues. For instance, the leftover soy meal can be utilized as animal feed or a soil supplement after the oil from the soybeans has been obtained for the manufacture of biodiesel.

Crop Rotation Strategies: Using crop rotation techniques that incorporate crops for food or animal feed in addition to crops used as feedstocks for biodiesel helps preserve soil fertility and lessens the environmental impact of monoculture methods.

B. Blending Waste Cooking Oils: Another hybrid strategy is to blend waste cooking oils with conventional vegetable oils or animal fats. This produces a more constant and dependable feedstock composition for the manufacture of biodiesel in addition to making use of waste resources. Careful quality control is necessary while blending various feedstocks to guarantee that the finished biodiesel product satisfies industry requirements. It is crucial to keep an eye on the fatty acid profile and other factors in order to preserve fuel quality [69].

Table 1. Overview of the origins and characteristics of the various oils used in the production of biodiesel

Group	Source of oil
Major oils	Coconut (copra), corn (maize), cottonseed, canola (a variety of rapeseed), olive, peanut (groundnut), safflower, sesame, soybean, and sunflower.
Nut oils	Almond, cashew, hazelnut, macadamia, pecan, pistachio and walnut.
Other edible oils	Amaranth, apricot, argan, artichoke, avocado, babassu, bay laurel, beech nut, ben, Borneo tallow nut, carob pod (algaroba), cohune, coriander seed, false flax, grape seed, hemp, kapok seed, lallemantia, lemon seed, macauba fruit (Acrocomia sclerocarpa), meadowfoam seed, mustard, okra seed (hibiscus seed), perilla seed, pequi, (Caryocar brasiliensis seed), pine nut, poppy seed, prune kernel, quinoa, ramtil (Guizotia abyssinica seed or Niger pea), rice bran, tallow, tea (camellia), thistle (Silybum marianum seed), and wheat germ.
Inedible oils	Algae, babassu tree, copaiba, honge, jatropha or ratanjyote, jojoba, karanja or honge, mahua, milk bush, nagchampa, neem, petroleum nut, rubber seed tree, silk cotton tree, and tall.
Other oils	Castor, radish, and tung.

 DOI : 10.35291/2454-9150.2024.0005

The detailed breakdown makes it easy to compare important characteristics, such as feedstock sources and appropriateness for biodiesel synthesis. This organized table is an excellent tool for academics and practitioners to select the finest feedstocks according to their unique characteristics. The addition of many oil sources enhances its capacity to provide a thorough review of the environmentally friendly alternatives for producing biodiesel.

X. PERFORMANCE OR EFFICIENCY OF BIODIESEL

For the Indian economy to function, encompassing the home, commercial, industrial, transportation, and agricultural sectors, energy is a vital necessity. Since independence, the country has become increasingly reliant on fossil fuels, including gas, oil, and coal, resulting in growing costs and possible shortages. This has raised concerns about the stability of the energy supply required for economic growth as well as environmental issues. The need to find alternative fuels has become imperative as fossil fuel supplies diminish. Because of the high demand for diesel in transportation, captive power generation, and agriculture, biodiesel, an engine fuel, is being considered as a substitute for diesel [70]. Biodiesel is made by alcohol and lipid acids interacting chemically, most commonly by mixing methanol and vegetable oil while a catalyst is present [71]. Because of its lower viscosity, it is better suited for use as motor fuel as opposed to pure vegetable oil. This paper will concentrate on biodiesel research and its impact on engine performance [72].

Renewable energy comes from indigenous sources and can thus help to reduce reliance on imports of oils while increasing supply security. The strategy aims to encourage the use of alternate renewable fuels, such as biomass fuels, in transportation [73]. In both oil-importing and developing nations, biofuels have the potential to open up new economic opportunities for rural residents. The central policy of biofuel is to create jobs, increase business efficiency, and protect the environment. Liquid or gaseous fuels primarily derived from biomass are known as biofuels, and they have the potential to be a sustainable and low-impact energy source. To make biofuel, the following ingredients are used: cereals, sugar beets, plant oils, organic waste, and processing [74].

Biodiesel, a renewable and cleaner-burning alternative to traditional diesel fuel, has gained prominence in the global quest for sustainable energy sources. As concerns about climate change and environmental impact mount, the performance and efficiency of biodiesel have become critical considerations in assessing its viability as a widespread fuel solution. This alternative fuel, derived from organic sources like vegetable oils and animal fats, offers potential benefits in terms of reduced greenhouse gas emissions and decreased dependence on finite fossil fuels. However, the global landscape of biodiesel production and utilization is complex, influenced by factors such as feedstock selection and regional regulatory frameworks [75]. The efficiency and performance of vehicles running on biofuels are influenced by several factors, including the energy content of biofuels, compatibility with existing engines, and geographic and climatic conditions [76, 77]. As the global automotive industry explores sustainable alternatives, the efficiency and performance of biofuels are subject to ongoing research and technological advancements aimed at achieving a harmonious balance between environmental benefits and practical implementation in various vehicle types and regions.

In terms of fuel efficiency, biodiesel, a renewable alternative to traditional diesel fuel, provides both advantages and challenges. Its lower energy content reduces fuel efficiency, but it also has cleaner combustion characteristics, lowering pollutant emissions such as carbon monoxide and particulate matter because higher blends may necessitate engine modifications or specially designed vehicles, biodiesel compatibility with existing diesel engines is critical [78]. Cold weather can also reduce the flow of biodiesel, potentially reducing efficiency. Winter blends and additives, on the other hand, can help to alleviate these problems. By utilising renewable resources such as vegetable oils or recycled cooking oil, biodiesel helps to create a more sustainable energy landscape. Addressing these issues and improving biodiesel efficiency remain critical goals in the pursuit of cleaner, more sustainable transportation solutions.

XI. ENGINE COMPATIBILITY

The transportation sector is experiencing a rapid reduction in reactionary energy reserves, leading to an increased demand for energy in machine machines [79]. Biodiesel, made from vegetable canvases and animal fats, offers several advantages over petroleum diesel energy, including biodegradability, non-toxicity, advanced flash point, lower exhaust emissions, and environmental benefits. In contemporary diesel engines, it can be utilized either pure or combined with petroleum-based diesel. However, biodiesel has downsides such as oxidative insecurity, poor low-temperature parcels, and a detergent-like property. Their chemical makeup explains the distinctions between petroleum diesel and biodiesel. Petrodiesel is made up of numerous different composites that boil at different temperatures, whereas the few composites that make up biodiesel are mostly Alkyl esters with a carbon chain length of 16–18, which are dependent upon the feedstock. Biodiesel contains central Triglycerides leftover after digestion: mono- and di-glycerides, and major adipose ester factors [80]. Experimenters can support long-term growth, energy conversion, effectiveness, and preservation of the environment by probing indispensable energies. Energy flows through three subsystems in a diesel machine energy system: energy feed, combustion, and exhaust. The combustion zone is the area where energy ignites and

 DOI : 10.35291/2454-9150.2024.0005

includes the cylinder block, cylinder liner, cylinder head, bay stopcock, exhaust stopcock, piston, piston rings, piston leg, and connecting rod [81].

Recent exploration has shown that degradation of biodiesel under common rail diesel machine operation doesn't disappear declination factors like oxidized biodiesel, TAN value, and water content [82]. Instead,the conductivity value and dissolved oxygen concentration of biodiesel samples vary dramatically. A new absorption system that incorporates energy renewal demonstrated better comity between biodiesel and FDM in normal operating circumstances. Prior to making a determination regarding the suitability of biodiesel and FDM for use in actual diesel engine operations, more research on machine operating conditions is necessary [83].

XII. COMPARISON WITH CONVENTIONAL DIESEL

Petrodiesel—commonly just called diesel—is a fuel composed of hydrocarbons that is obtained from crude oil by refining. It is a crucial source of energy used worldwide to run a variety of automobiles, industrial equipment, and power-producing systems. Hydrocarbons, which are molecules made of hydrogen and carbon atoms, comprise the majority of the components of biodiesel. These hydrocarbons fall into three categories: aromatic hydrocarbons, which include cycloalkanes (the naphthenes), and alkanes (paraffins) [84, 85]. The specific composition of crude oil can be influenced by both its source and the refining processes. Due to the high sulfur content of diesel fuels in earlier times, sulfur dioxide was released during combustion [86]. But in order to ensure compliance with strict environmental regulations, contemporary diesel fuel that contains ultra-low sulfur (ULSD) is one kind that goes through desulfurization procedures [87]. As a result, sulfur emissions from burning diesel have significantly dropped. The level of diesel fuel's strength ignition is gauged by the cetane number. It indicates the ease with which the fuel ignites during combustion. A higher cetane number generally corresponds to better ignition characteristics. Petrodiesel typically has a cetane number within a specified range to ensure optimal engine performance [88]. Nitrogen Oxides (NOx), particulate matter (PM), and particulate matter (PM), carbon dioxide (CO_2) and are among the pollutants produced by burning petroleum-based fuel. Human health and air quality may be negatively impacted by PM and NOx [89]. To lower these emissions, advanced pollution control technologies are employed, Like diesel particulate filters (DPF) and selective catalytic reduction (SCR). The amount of sulfur in diesel fuel has been a significant environmental concern due to its role in forming sulfur dioxide (SO_2) during burning. Ultra-low sulfur diesel (ULSD) has become the standard in many regions, leading to significant reductions in sulfur emissions [90].

In the place of conventional petrodiesel, biodiesel is a sustainable and renewable fuel that comes from biological sources, including leftover cooking oil, animal fats, vegetable oils, and, more recently, microorganisms like algae. Contrary to popular belief, biodiesel is a fuel that is created utilizing biological sources and is renewable. The initial step in the production process is to choose adequate feedstocks, such as tossed cooking oil, animal fats, non-food crops like jatropha, and vegetable oils (canola, soybean). Triglycerides and alcohol react chemically with a catalyst present during the transesterification process, which is the most common way to produce biodiesel. Combined with glycerol, this process produces biodiesel, which must then be refined and purified to fulfil quality standards [91]. Depending on the type of alcohol used in the transesterification process, the majority of biodiesel is either fatty acid methyl esters/fatty acid ethyl esters. Fatty acids that are found in the feedstocks are the source of these esters. Compared to petrodiesel, biodiesel emits less fine particulate matter and other pollutants and has a lower sulfur content. When compared to petrodiesel, burning biodiesel typically produces fewer emissions of greenhouse gases as well as lower amounts of sulfur oxides and particulate matter. In keeping with the organic carbon cycle, the carbon released during the burning of biodiesel lowers the total carbon footprint. With just a few modifications, diesel engines may run on biodiesel as fuel., which is its primary application. It can be used as pure biodiesel (B100) or in various ratios (B5, B20) in conjunction with petrodiesel [92]. Along with that, biodiesel is used in power generation, industrial machines, and residential heating.

According to the European Biodiesel Standard, fuel is designated as fatty acid methyl esters (FAME). According to the ASTM biodiesel standard, "biodiesel" is "fuel made from long-chain fatty acid mono-alkyl esters, or FAME, that originate from oil and fats of vegetable and animals and are assigned "B100" [93]. The transesterification method, which is used to separate this fuel from oil or fat, produces glycerol as a byproduct. One could contend that when methanol is used as an alcohol component in the production of biodiesel, approximately 95% of its carbon atoms are "bio". The cause underlying this is that methanol originates primarily from non-renewable natural gas; however, can also be created from renewable resources. Since ethanol is typically produced from renewable resources like corn and sugarcane, biodiesel is 100% "bio" in terms of ethyl esters. Nevertheless the bio prefixes can be used to denote the fast dissipation of biodiesel fuel. In any event, this is the widely acknowledged definition of biodiesel on an international basis. By way of example, contrasted with biodiesel produced from canola (soybean or rapeseed) oil, which has fewer saturated esters, biodiesel made from jatropha has poorer cold flow behaviours due to its 20–25% concentration of Methyl esters of saturated fatty acids C16 and C18 equivalent to the source of

 DOI : 10.35291/2454-9150.2024.0005

methanol in the methyl esters manufacturing process, the source of hydrogen, which can come derived from both non-renewable and renewable resources, poses a challenge for sustainable diesel. In many scientific journals, hydrotreated vegetable oil is another name for renewable diesel.

Moreover, biodiesel boasts a much more volatile than petrodiesel. The petrodiesel standards have lower flash point requirements than the biodiesel standards [94]. The boiling temperatures of the constituent ingredients are primarily expressed in this. In this regard, the boiling points of hexadecane and decane are 287 and 174 °C, respectively, whereas methyl palmitate and methyl decanoate are 417 and 224 °C, as well [95]. The flash point of the petrodiesel is lowered due to the lower boiling point of its branched and components that have lesser molecular masses. Yet, the flash point can be impacted by the alcohol that is used to produce biodiesel and that is present in minute quantities in the finished product. The biodegradability of environmental issues and their influence on exhaust emissions.

The "ideal" constituents of the intricate mixture known as biodiesel are straight-chain alkanes. Hexadecane, also known by its less fancy term, "cetane," is, in fact, the cetane scale's more accurate reference compound—a notion akin to the gasoline octane number and connected to the diesel fuel's ignition quality. Typically, petroleum diesel comprises alkanes, branched alkanes, aromatic compounds with one or more aromatic rings, and alkyl side chains [96]. On the other hand, branched compounds have lower cetane numbers. A highly branched example of this is 2,2,4,6,8,8-heptamethylnonane, with a lower melting point, is the reference chemical of poor quality over the cetane scale [97]. Alkylcycloalkanes and Alkylaromatics have lower cetane numbers and low melting temperatures, which rise with side chain length. The sulfur-containing compounds added to the widely used ultra-low sulfur diesel (ULSD) fuels are dibenzothiophenes with alkyl (usually methyl) substituents that were extracted from petrodiesel. Small oxygen- and nitrogen-containing compounds gave petroleum diesel its lubricity; these molecules are eliminated during the process of hydro-desulfurization, which produces ULSD fuels [98]. For this reason, ULSD fuels are ill-lubricated Biodiesel at a rate of 2% or more can be used to restore lubricity, lubricity additives, however, can also improve lubricity and in certain situations may also be based on lipid feedstocks. The goal is to reproduce the qualities of petrodiesel by enriching renewable diesel fuels with long-chain alkanes, the "ideal" constituents of petrodiesel. If long-chain alkanes make up the majority of the fuel, renewable diesel possess an elevated cetane number; on the other hand, if it includes a lot of lower cetane number in shorter-chain and isomerized species. According to reports, renewable diesel has a high cetane number. Long-chain alkanes are not preferred over shorter-chain and isomerized compounds because of their inferior low-temperature properties. The renewable diesel's cloud point that was tested for emissions from exhaust was reported to be 7 C, but it has typically been reported to be ranging from 5 to 25 or 30 C, depending on the "additional catalytic processing" or "severity" of the production process. Since the smaller (and/or branched) molecules required having a lower CN for improved cold flow, renewable diesel appears likely to exhibit reduced CN with improved cold flow properties.

XIII. ECONOMIC ASPECTS

Profitable aspects Biofuel programs are critical to both profitable growth and the environmental impact of biofuels [99]. The current generation of biofuels, which are different and evolving, has a significant impact on food requests and the terrain. Long- term consequences are determined by factors similar as investment in technological change, population and profitable growth, climate change, and long- term programs towards energy, husbandry, and the terrain [100]. Alternatives similar as navigator beach petrol product, coal and gas liquefaction, mongrel electric vehicles, energy effectiveness, and mass conveyance should be considered in the environmental assessment of biofuel.

Increased income in developing countries increases demand for both food and energy, reducing food supplies and affecting food security programs that increase force, such as increased agrarian exploration and less strict regulation of agrarian biotechnology, can ameliorate this. Biofuels can help to ameliorate energy security by diversifying physical energy sources, reducing reliance on trade with unpredictable regions, and lowering hothouse gas (GHG) emigrations. While biofuels emit smaller GHGs than fossil energies, the net GHG effect is uncertain due to circular emigrations and a lack of clarity onnon-GHG environmental impacts. Biofuels are also replenishable, unlike technologies that calculate on natural gas and coal, similar as energy cells and electric vehicles.

Biofuels have the eventuality to increase ranch income, produce new jobs, and close the oil painting force- demand gap [101]. They bear further labour than other energy technologies to produce and convert, and their product and conversion bear further labour than fossil energies or other industrially grounded technologies. This can affect in pastoral development and increased income. While biofuels emit smaller GHGs than fossil energies, the net GHG effect is uncertain due to circular emigrations and a lack of clarity onnon-GHG environmental impacts [102]. Biofuels are also replenishable, unlike technologies that calculate on natural gas and coal, similar as energy cells and electric vehicles. Biofuels have the eventuality to increase ranch income, produce new jobs, and close the oil painting force-demand gap. They bear further labour than other energy technologies to produce and convert, and their product and conversion bear further labour than fossil energies or other industrially grounded technologies. This has the implicit to lead to pastoral development and increased income.

 DOI : 10.35291/2454-9150.2024.0005

ISSN : 2454-9150 Vol-09, Issue-10, Jan 2024

Because biofuels have physical and chemical parcels analogous to oil painting, they're affordable to acclimatize to biofuel-grounded infrastructure. However, wide biofuel relinquishment may place fresh strain on being land use, food product, and natural territories, as well as increase demand for agrarian inputs [103]. Biofuels, by adding energy force, have the eventuality to undermine sweats to manage demand through energy effectiveness and conservation.

The term" biofuels" is divided into" traditional" and" ultramodern" biofuels, with traditional biomass account for 80 of global renewable energy use and ultramodern biomass utilising more sophisticated conversion technologies similar as gasification and turmoil [104]. Traditional biomass accounts for 80 of all renewable energy consumption worldwide, while ultramodern biofuels regard for lower than 1. In 2004, global energy product was roughly 440 quadrillion Btu2 (11000 mtoe), with transportation account for 21 and electricity account for 30. The consequences of large investments in developing ultramodern biofuels are unclear and contentious [105].

This check focuses primarily on liquid biofuels, which are one of the swift-growing indispensable energy sources moment. Table 2 provides an all-inclusive evaluation of the various aspects of biodiesel's effects, including social, economic, environmental, and energy security aspects. The methodical delivery makes it possible to quickly understand the complex connections between the production of biodiesel and its many applications. Understanding the intricate relationships between energy policies and their effects on the environment, economy, and society is made much easier with the help of this resource.

Table 2 .Various impacts of biodiesel

Economic & social impact	Environment impact	Energy security
Sustainability; made from agricultural or waste resources	Reduced 78% GHG emissions	Reduced dependence on fossil fuels
Fuel diversity & improved fuel efficiency & economy	Reduced air pollution	Domestic targets
Improved rural economy	Biodegradability	Supply reliability
Increased income tax & trade balances	Improved land & water use	Readily available
International competitiveness	Carbon sequestration	Renewability
Increased investments on feedstocks & equipment	Lower sulfur content	Domestic distribution
Technological developments (R & D)	Lower aromatic content	Improved fuel economy
Higher cetane number (52 vs. 48), lubricity & flash point	Lesser toxicity	Comparable energy content (92.19%)
Knowledge development & diffusion	Safer handling & storage	Strict quality requirements are met
Strong growth in demand & market formation		Viscosity 1.3 to 1.6 times that of D2 fuel

XIV. COST OF PRODUCTION

Made mostly of the methyl esters of adipose acids, biodiesel is a sustainable diesel energy source that is derived via fats and canvases [106]. An installation of a comparatively small artificial biodiesel product has its operating and capital expenses estimated by means of a computer mode. i.e. Transesterification, an ester and glycerol recovery, and continuous vegetable oil were the primary operations performed in the factory. Using current machinery, reagent, and force costs as well as current product practices, the model was created using modern process simulation software. The established raw materials was crude, degummed soy bean oil for applying it.

The factory's periodic product capacity was established at 10 × 106 girls. The anticipated price of setting up and building was a total of 11.3 million USD. The biggest expenses for the outfit, taking accountability for almost a-third of the total, were the storehouse tanks, which were designed to hold feedstock and product for 25 days [107]. To use as a supply chain, soybean oil painting, a predicted cost of US$0.52/kg ($0.236/lb) resulted in a US$0.53/l ($2.00/girl) biodiesel product. The cost of the oil artwork feedstock, which accounted for 88 of the total estimated product costs, was the single largest contributor to this value. Through an analysis of their dependence, it was discovered that there was a close relationship between the costs of the feedstock and the product; the change in the cost of the oil artwork was equivalent to US$0.020/l (or US$0.075/girl) change in the product's cost. Product costs were nearly six times lower because of the recovery of co-product glycerol produced during the biodiesel product and its trading into the marketable glycerol request as an 80 w/w waterless result [108]. The biofuel product's cost was

 DOI : 10.35291/2454-9150.2024.0005

intended to move in tandem and linear fashion with variations in the glycerol request value, increasing by US$0.0022/l (or US$0.0085/girl) for every US$0.022/kg (or US$0.01/lb) decline in the glycerin value. Biodiesel technology is moving from an exploratory project to a globally utilised venture. The amount of biodiesel produced has increased significantly recently, and It is anticipated that this trend will continue, supporting the increased use. Right now, the US and Europe are the top producers of biodiesel, with 114 million litres produced in the US in 2004 and 1.7 × 109 l (450 million girls) in Europe in 2003, respectively. The establishment of new product stores and the rise of being bones are the causes of this growth.

Finally, it should be noted that biodiesel is a rapidly expanding around the world product that uses feedstocks derived from renewable agricultural practices. The selection of feedstock is dependent upon various aspects, such initial value, expenses, government backing, and energy efficiency. Reducing product costs and promoting sustainable energy use depend significantly on the advancement of innovations that enable the use of lower value raw materials. Bioenergy sustainability is vital for reducing hothouse gas emigrations and guarding biodiversity. Strict sustainability standards for biofuel and bioliquids have been established by the European Union EU), icing that these bioenergy's can't be produced from raw paraphernalia attained from land with high biodiversity [109]. Microscopic algae, a biomass of terrestrial plants, have the potential to produce bioenergy similar to biodiesel because of their high productivity, potential to improve food security, and rivalry with pastoralist farmland. Because of their sophisticated ability to repair carbon dioxide (CO_2) emitted by sources of carbon, such as sedulity-sourced CO_2 and primary feasts from archconservative-energy power shops, cyanobacteria are more effective than terrestrial plant sources.

In addition, they can be grown more sustainably in terms of water use and utilised as a substrate for higher value co-products such as food additives and medicines. Due to their enhanced ability to produce neutral carbon-rich lipids similar to Triacylglycerol (Marker) with CO_2 and solar energy, microalgae as substrates for biodiesel products have greater advantages over biomass from terrestrial plants [110]. The vacuity of feedstock paraphernalia similar to micro algae biomass and lipids, synthetic processing/birth technique, and output of quality microalgal biodiesel are recognised as three crucial cost- contributing factors for successfully producing biodiesel from microscopic algae. These elements account for a sizable portion of the micro algae biodiesel's total product cost (which is approximately > 80). Three key molecular approaches could be used to address these issues: maximising outcomes of lipids and microalgal biomass as a biodiesel emulsion feedstock, reducing the amount of synthetic processing that takes place during the production of commodities based on biodiesel, and improving the quality of biodiesel for ideal machine operation. To optimize the economics of microalgal biodiesel, the main attainable objectives are to increase the yields of microalgal biomass and lipids as a feed substrate for biodiesel emulsion, reduce synthetic processing lodging processes of biodiesel products, and optimize biodiesel quality for its machine performance [111]. Animal and plant fats, as well as leftover cooking oil, are used to make biodiesel, an alternative diesel fuel. But prior studies haven't shown a method that makes algae farms on non-arable land economically feasible for large-scale production. Among the problems include variable market pricing, erratic algal productivity, ambiguous capital and operating expenses, and unclear degrees of government assistance. This study highlights the need for more research and development in this crucial step in the manufacture of alternative fuels by providing a current financial analysis of the economic and production aspects that could significantly impact the biodiesel processing industry's success [112].

XV. MARKET TRENDS FOR BIODIESEL

Biodiesel, a renewable alternative to conventional diesel fuel, has seen dynamic market trends across the world, driven by environmental concerns, energy security, and the search for sustainable energy sources. Usually, renewable resources like vegetable and animal fats and residual culinary oils are employed to make this biofuel [113]. The worldwide biodiesel industry has seen significant growth, influenced by legislative frameworks, technical breakthroughs, and variations in consumer tastes. We dig into the multiple market trends of biodiesel in this detailed analysis, evaluating major drivers, difficulties, regional dynamics, and prospects for the future.

Enhancements in the economics and ecological impact are among the benefits that advancements in technology continue to offer. Not to displace fossil fuels, but to help create an integrated strategy is the goal of biodiesel. With extended diesel usage, biofuel has been designed to be a suitable replacement. The main goal of biodiesel is to help local communities and provide energy security. We need biofuels for each of these six reasons.

Direct rely on to utilize:

The fact that biofuel can be used in today's engines, infrastructure, and vehicles despite the need for any modifications is one of the main reasons why it is necessary. Biofuel is similar to petroleum diesel fuel in that it can be pumped, burned, and preserved. It is safe to use both pure and blended forms of it. Biofuel will improve fuel economy because it is year-round and nearly identical to petroleum fuel [114].

Fuel lines in older, over fifteen-year-old cars must be replaced, but biofuel can cause the lines to fracture Deposits in fuel tanks may result from using biofuel. There won't be any issues when the user switches between

 DOI : 10.35291/2454-9150.2024.0005

petroleum and biofuel as needed. The energy security that biodiesel serves as:-

Energy safeguarding is critical for a country's stability and development, and biodiesel can help to improve that security. Biodiesel, a renewable and domestically produced fuel, has numerous advantages, including domestic production, energy source diversification, geopolitical vulnerability reduction, rural economic development, climate resilience, energy independence, and energy infrastructure resilience [115]. Its diverse feedstocks, such as soybeans, rapeseed, and sunflowers, enable countries to develop a robust and self-sufficient biodiesel production infrastructure, reducing reliance on foreign oil markets and increasing agricultural independence.

Biodiesel also helps to reduce geopolitical risks by reducing reliance on oil imports, resulting in a more stable and secure energy supply. It also promotes rural economic development, thereby addressing social and economic disparities and fostering a more inclusive and resilient national economy [116].

XVI. USE OF BIODIESEL IN ECONOMIC DEVELOPMENT

Biodiesel, a renewable and cleaner alternative to conventional diesel, contributes significantly to economic development by stimulating growth in a variety of sectors [117]. This renewable and cleaner alternative addresses environmental concerns while also providing economic opportunities that benefit both local and national economies. Keyways in which biodiesel contributes to economic development include job creation and employment opportunities, agricultural sector growth, energy independence and trade balance, infrastructure development, technological innovation and research investment, and the growth of SMEs, or small and medium-sized businesses.

Biodiesel industry creates jobs throughout the value chain, from farmers growing biofuel crops to workers in biodiesel production facilities and distribution networks [118]. This diversification of agricultural activities stimulates growth in rural areas, contributing to increased income for farmers and supporting the overall economic development of rural communities.

Investments in biodiesel infrastructure led to the development of industrial clusters and economic zones, attracting further investment. Overall, biodiesel contributes to a knowledge-based economy and encourages small and medium-sized businesses to expand.

XVII. ENERGY EQUILIBRIUM

The ratio of the energy needed to generate, manufacture, and distribute fuel to the energy released during combustion is known as the fuel's energy balance [119,120]. In comparison to other fuel substitutes, biofuel exhibits a high energy balance, which is a significant consideration as energy security becomes a more important issue for governments and societies worldwide. The nation's economy will collapse in the absence of a consistent supply of reasonably priced energy since there won't be any for power plants, transportation, or home heating. By utilizing domestic energy crops, biofuel can enhance energy security and balance. The plants are used to make biofuel, which takes the place of crude oil imports.

The widespread use of biodiesel represents a transformative opportunity that combines environmental sustainability, economic development, and energy security. It provides a renewable alternative to conventional diesel fuel, improving energy balance by addressing feedstock sustainability, economic viability, affordability, technological innovation, and global energy security [121]. Sustainable sourcing, economic viability, and affordability of biodiesel are critical for its growth. Transesterification and enzyme-catalyzed methods, for example, improve efficiency and lower production costs. It also helps to ensure global energy security by reducing reliance on volatile oil markets. Furthermore, biodiesel's ability to create jobs and promote social equity is an important factor in achieving energy equilibrium.

XVIII. RECYCLABLE AND BIODEGRADABLE

Because of its properties, biofuel has been demonstrated to be less toxic than diesel in terms of potential environmental harm and damage. It has been discovered that biofuel is less toxic than table salt because it is a naturally occurring, non-toxic vegetable oil. Moreover, biofuel has a 15-fold lower toxicity than common fish species [122]. Because biofuel has less volatility than petroleum fuel, it has been shown to be safer to handle. The fuel will produce enough vapour to ignite due to the high energy, so there is a chance of an unintentional ignition. Used cooking oil is among the many fats and oils that can be used for this purpose [123]. Their value will rise, and they will become more economical with recycled oils. This contributes to the numerous advantages that a growing biofuels market offers. By 2020, the amount of green fuels used in Europe is predicted to rise.

Biodiesel production is a promising and sustainable alternative to conventional diesel, providing a more environmentally friendly option. Its recyclability and biodegradability make it an environmentally friendly fuel option, reducing the environmental impact of energy production and consumption [124]. Biodiesel is inherently biodegradable, allowing it to be broken down into simpler, non-toxic compounds by environmental microorganisms. Because it is produced using renewable feedstocks like vegetable and animal fats and recycled cooking oils, the environmental impact of extracting and processing crude oil is minimized, as is the depletion of finite fossil fuel reserves. Biodiesel is also carbon neutral and has a closed carbon cycle, lowering the risk of spills and associated environmental hazards [125].

 DOI : 10.35291/2454-9150.2024.0005

It is less difficult to handle and dispose of than traditional diesel, and its compatibility with existing infrastructure enables seamless integration into current transportation and energy systems [126]. Biodiesel also emits fewer greenhouse gas emissions than conventional diesel, helping to mitigate climate change. Ultimately, biodiesel's natural environmental friendliness makes it a crucial component of the shift to a future with more sustainable energy sources.

CHALLENGES AND FUTURE PROSPECTS

In the early 2000s, there were high hopes for biofuels to replace fossil fuels in transportation and aid in lowering of greenhouse gas emissions [127]. Limited feedstocks for biofuel production, moderate ecological performance, high costs (relative to fossil fuels), and competition with food production are the main obstacles to further biofuel expansion [128]. It focuses on the three key areas for biofuel creation and application right now: the United States, the European Union, brazil which together accounted for nearly 75% of the world's supply of biofuels in 2010 [129]. Our strategy is predicated on a dynamic framework for the economy that takes into account the primary biofuel cost components as well as the associated technological learning in terms of capital costs.

The main conclusions are as follows: (i) All fuel types should be subject to a CO_2-based tax system, which would give fossil fuels and renewable fuels a level playing field in terms of environmental incentives (ii) More research and advancement is needed to determine the true market value of biofuels, particularly second-generation biofuels. Biodiesel, which is produced from biological sources like algae, animal fats, and vegetable oils, is a renewable fuel alternative to diesel. However, challenges such as feedstock availability and competition, which can lead to competition with food production and deforestation, are present. Biodiesel production expansion may result in land use changes, which may have negative environmental consequences. The higher production costs than traditional diesel make economic viability less likely [130]. Because biodiesel has different properties than traditional diesel, storage tanks, pipelines, and fueling stations must be modified. In cold climates, cold flow properties can affect biodiesel flow properties, requiring the use of additives or blending with conventional diesel.

The need for further technological advancements to improve efficiency and reduce costs is one of the technological challenges. Future prospects include the development of advanced feedstocks from non-food sources such as algae and waste materials, as well as the production of second and third-generation biodiesel from algae [131]. Government policies, incentives, and subsidies can encourage the development and use of biodiesel. Environmental regulations, as well as growing public awareness of the environmental impact of fossil fuels, can drive demand for cleaner, renewable fuels such as biodiesel. Technological advancements can result in more efficient and cost-effective processes, making biodiesel a more appealing commercial option.

Global initiatives and public awareness of environmental issues may drive biodiesel demand. Despite these obstacles, ongoing research, technological advances, and supportive policies can all contribute to the growth and sustainability of the industry. Fuels derived from petroleum have finite supplies that are concentrated in particular global regions, and their peak production is approaching. Biomass sources are becoming more attractive due to the finite supply of traditional fossil fuels, rising emissions of pollutants produced during combustion, and rising costs [132]. Globally, biodiesel is becoming more and more popular as a direct substitute for diesel fuel in automobile engines or as a blending ingredient. Biodiesel is a concoction of FAME made from a renewable lipid feedstock, like vegetable oil or animal fat.

Because of its relatively high heating values (HHVs), biodiesel is an ideal option for diesel fuels in diesel-powered engines [133]. Edible vegetable oils, such as those from soybeans, rapeseed, and palms, are the main source of feedstock for first-generation biodiesel. However, the usage of edible oils as a source of energy has sparked opposition from public and from non-governmental organisations. Jatropha curcas L. is one type of non-edible oil that can be used to make second-generation biodiesel, which has become a popular alternative feedstock for the biodiesel industry. Since jatropha oil shares characteristics with edible oils, it does not necessitate large changes to equipment and process flow [134]. It also has the benefit of being easily produced on non-arable or barren terrain. However, because jatropha oil contains greater levels of free fatty acid (FFA), it may necessitate extra procedures used before treatment [135].

To overcome these shortcomings, researchers continue to look for a more eco-friendly feedstock for biodiesel, with microalgae being recognised as one of the oldest living creatures on the planet. Microalgae grow extremely quickly, can quadruple their biomass in less than a day, and can store significant amounts of lipid within their cells, which biodiesel can be made from. The biofuel industry is confronted with a number of unknowns, such as competition from alternative fossil fuels and environmental concerns with yields ranging from EU rapeseed that requires 100 gallons per acre, US corn requires 400 gallons per acre, and Brazilian sugarcane requires 660 gallons per acre., the land intensity of current biofuel production is a serious cause for concern.

The production of cellulose ethanol from decomposing plant matter has the potential to drastically lower the amount of land needed [136]. The most commonly found biological material is cellulose, which can be found in materials that are cheap, like wood chips, grasses, crop residues, and garbage from municipalities. Compared to corn ethanol, which costs $1.65 per gallon, the cost of

 DOI : 10.35291/2454-9150.2024.0005

producing cellulosic fuel in the United States is currently over $2.50 [137]. The results of harvesting crop residues, trees, and grasses as well as the logistical and environmental costs of processing large quantities of bulky feedstock are additional costs associated with cellulosic ethanol production that need to be evaluated.

XIX. TECHNICAL CHALLENGES

The biodiesel industry is expanding quickly, and there is discussion over the possible financial advantages of using biomass to produce biodiesel in arid areas [138]. The main objective has been to identify species of plants that have characteristics particularly well-suited to the biodiesel industry and capable of generating substantial quantities of triglycerides in environments that are arid. Investigation on the advancements in technology required for converting triglycerides towards biofuels without employing a large amount of water, which is right now needed, is restricted.

Production of glycerine as a byproduct poses a significant issue as well because it must be separated fr om biodiesel using a lot of water in order to be utilised in motor engines [139]. Triglyceride cleavage into its constituent fatty acids, hydrotreating, and elevated dilution with petrodiesel (<10%) are the three primary techniques that are frequently used to lower the viscosity of vegetable oil for diesel engines. Later on, One can carry out the cleavage either with the production of glycerine as a byproduct or by incorporating the glycerine into the biofuel through a number of recently created techniques. Because of the growing disparity between the supply and demand of edible oils in many nations, using them to make biodiesel is not practical in the near future. Biofuels would provide substantial advantages should they have been grown on marginal land, needed little energy to convert feedstocks into biofuels, or produced their biomass using the fewest possible agricultural inputs (i.e., less energy, water, fertilizer, and pesticide).

The "water intensity" standard, which is measured in litres of water per kilometre travelled, has been introduced to evaluate the effects of biofuels on water withdrawal and usage associated with the creation and application of fuels for transportation [140]. The light-duty vehicles that run on conventional petroleum-based petrol and diesel, as well as non-irrigated biofuels, possess the lowest rates of water withdrawal and consumption. Electricity produced from nonthermal renewable sources and hydrogen produced from electrolysis of methane or electricity produced through electrolysis. It is challenging to replace fossil fuels with renewable energy sources because, despite the possibility of high water costs associated with biofuel production, these fuels seem to be a mitigation strategy for CO_2 emissions [141].

Because of its increased lubricity and longer engine life, biodiesel is a biodegradable, non-toxic fuel alternative that doesn't require modification to run in diesel engines. Using KOH and NaOH as homogenous catalysts, for every triglyceride molecule, the traditional process of making biodiesel yields three fatty acid methyl esters and one glycerol molecule [142]. One mole of glycerol (GLY) and three moles of fatty acid esters are produced by a transesterification reaction involving one mole of triglyceride and three moles of alcohol.

However, because it calls for the separation, neutralisation, and thorough washing of the finished mixture, this process is not environmentally friendly and produces waste such as wastewater and salt residues [143]. Furthermore, the catalyst cannot be recycled, raising the overall cost of producing biodiesel and lowers the glycerol obtained as a by-product's quality. The most appealing and widely used process for producing biodiesel is now alkaline transesterification of vegetable oils [144]. This process uses uniform base catalysts, such as NaOH and KOH, and moderate heating temperatures (50–60°C). As more environmentally friendly options, there have been reports on the production of biodiesel using solid acids, heterogeneous base catalysts, enzymatic protocols, and other chemicals.

Finally, it should be noted that various methods are employed to produce biodiesel from vegetable or leftover cooking oils as well as from animal fats. An important step in providing a non-toxic, biodegradable substitute for petrodiesel that prolongs engine life and lowers maintenance costs is the methanolysis reaction.

XX. RESEARCH AND DEVELOPMENT

The article proposes a methodical approach to assessing potential R&D pathways for biodiesel production. The pathway candidates undergo scrutiny using an imprecise optimization approach that takes note of the various factors that underlie (SHE) and economic performance (EP) objectives. The results of this assessment indicate that the most ideal method for producing biodiesel is enzymatic transesterification from waste oil. There are several suggested and discussed improvement measures for the intrinsic SHE in biodiesel production. The objective of these improvement initiatives is to raise standards for environmental, health, and safety throughout the biodiesel production process.

Biodiesel is another noteworthy renewable fuel that can assist in addressing environmental concerns and meeting the world's energy needs. Early risk evaluation is extremely helpful when the process is still being researched and designed, as it makes changes that minimize or remove dangers easier and more economical. This work examines the intrinsic safety, health, and environment (SHE) and economic performance (EP) of biodiesel production from the very beginning of the process lifecycle, or research and development (R&D).

The inherent SHE assessments are carried out using the generally recognized methods for inherent safety, health,

 DOI : 10.35291/2454-9150.2024.0005

and environmental friendliness: the Inherent Environmental Toxicity Hazard (IETH), the Prototype Index of Inherent Safety (PIIS), and the Inherent Occupational Health Index (IOHI).

Innate well-being

ILO statistics from 2013 illustrate that illnesses associated with work account for a greater number of deaths than industrial accidents. Thus, it is impossible to overlook the risks to occupational health in the chemical industry. There are extremely few intrinsic occupational health evaluation approaches available as compared to safety and environmental methods. The EHS method stands for Environment, Health, and Safety is the oldest inherent occupational health analysis technique among [99]. Other techniques, such as the Inherent Benignity Indicator (IBI), Process Route Healthiness Index (PRHI)), and The Occupational Health Hazard Index (OHHI), came later. Still, IBI and EHS are inappropriate for intrinsic occupational health assessments since they take into account fewer health-related factors than other goals, like safety and environmental considerations [101]. Likewise, when comprehensive and precise data are needed for R&D, OHHI and PRHI are not acceptable. It should be noted that there are extremely few techniques available for evaluating innate health and even fewer for assessing production pathways. This work uses IOHI in conjunction with other techniques to evaluate the sustainability of the biodiesel production process throughout the stages of research and development [94].

Comprehensive assessment of intrinsic SHE

It was suggested Utilizing the analytical hierarchical process (AHP) to engineer sustainable development (ESD) technique in a study on alternatives to biodiesel synthesis [104]. Investigators conducted their analysis by taking into account a variety of variables, such as safety and health regulations and ecological, social, and economic considerations. The analytical process hierarchy (APH), a modular technique, was utilized by researchers to evaluate and build a sustainable biodiesel manufacturing process [108]. Be informed that those approaches are more suited for use early on of engineering design than in the process research and development stage. This is because the evaluation often needs certain data, such as a equipment architecture, mass and energy balance, flowsheet, etc. Most operation units of international organizations agree that, while developing a system, the whole SHE should be considered rather than simply the economic one. Many techniques have been developed for intrinsic SHE evaluations; the following explains a few of them: A method for intrinsic SHE assessment was presented at the process flowsheeting stage [110]. The effects of intrinsic SHE are evaluated using twelve different categories, but the effects of collective hazards are evaluated using a single marker called the possibility of risk. The INSET toolset was eventually created by the Project INSIDE (2001) for evaluating intrinsic SHE. An additional method called the Integrated Inherent Safety Index (I2SI) suggested engineering sustainable development (ESD) using the analytical hierarchy process (AHP) technique in a study on alternatives to biodiesel synthesis [116]. When conducting their investigation, investigators took into account a number of factors, including ecological, social, and economic concerns in addition to health and safety regulations .Also researchers evaluated and created a modular analytical process hierarchy (APH) technique-based sustainable biodiesel manufacturing method. Please note that those methods work best when applied early in the engineering design process rather than during the process of research and development. This is why the evaluation often needs certain data, such as a flowsheet, mass and energy balance, equipment construction, etc.. Recent studies made the point that when doing an assessment with several objectives, it is more crucial to give each assessment parameter equal weight than to give it a distinct priority [115]. The main objective of this study is to create a systematic method for the intrinsic SHE evaluation of biodiesel manufacturing in order to overcome the aforementioned difficulties.

Despite its importance to humans and the environment, there are currently limited techniques accessible to evaluate the intrinsic SHE in the chain of biodiesel production. This study conducted a sustainability analysis at the beginning of the research and development phase of the biodiesel production pathway. The conceptual framework that outlines an extensive strategy for evaluating intrinsic EP and SHE on the route leading to the manufacturing of biodiesel was introduced. First, eight routes for producing biodiesel utilizing fresh vegetable or waste oil through base-catalyzed, acid-catalyzed, enzymatic, and supercritical transesterification are categorized. The proposed simple formula is employed for EP assessment, whereas three renowned methods—the IOHI, IETH, and PIIS—are used for inherent SHE assessment. It was demonstrated by the assessment that the basic data from the R&D stage was adequate for the evaluation. In addition, the fuzzy optimisation approach is used to adequately evaluate all objective factors. Based on the findings, the most sustainable manufacturing strategy is proposed to be enzymatic transesterification using waste vegetable oil (ki of 0.3592). This is primarily due to the use of fewer chemicals and less dangerous operating conditions, together with lower waste oil costs. Instead, production pathways with higher chemical content and harsher operating conditions, like acid-catalyzed esterification followed by base-catalyzed transesterification and supercritical transesterification, are found to be completely unsustainable. In the end, several inherent-based techniques were put forth to raise the intrinsic SHE performance of the biodiesel production pathway. Potential suggestions among these include using less drastic response conditions (nearer to atmospheric conditions), Increasing process yield and

 DOI : 10.35291/2454-9150.2024.0005

substituting less hazardous chemicals for hazardous ones (such as ethanol from methanol) can help lower the amount of chemicals required in the reactor.

XXI. CONCLUSION

Coal, oil, and natural gas are among the fossil fuels that provide the majority of the energy used worldwide. These fuels are anticipated to run out in 65 years and are extensively used in daily life. In place of diesel fuel derived from petroleum, biodiesel is a clean, biodegradable, and environmentally beneficial fuel. Nevertheless, before biodiesel becomes a practical substitute, technological challenges including the high cost of triglycerides, the requirement for less expensive raw materials, and the requirement for biotechnology techniques must be fixed. Due to its production from renewable resources including animal fats, cellulosic biomass, and genetically engineered crops, biodiesel offers environmental sustainability and lower carbon footprints. It increases energy security, improves air quality, and reduces sulfur emissions.

Biodiesel is more easily incorporated into social, economic, and environmental stability due to its extended lifespan and possibilities for integrated biorefinaries. With 4.6 billion tonnes of biodiesel generated annually in the US from plant-based oil and animal fat, biodiesel has the potential to drastically reduce emissions from diesel fuel made from petroleum. Biodiesel has more promise because of its closed carbon cycle and renewable nature, which also reduce reliance on imported fossil fuels, create a market for surplus fats, and reduce airborne particulates. The amount of biodiesel produced can be altered in response to a number of variables, including economic feasibility and environmental considerations. Overcoming technological barriers like the high expense of using virgin plant-based oil as a source of fatty acids is necessary to make biodiesel. To speed up the process and produce high-quality biodiesel, employ inexpensive feedstocks such animal fats, leftover frying oils, and non-edible oils, or alkaline catalysts like sodium methoxide ($NaOCH_3$), potassium hydroxide (KOH), sodium ethoxide ($NaOCH_2CH_3$), and sodium hydroxide (NaOH).Compared to regular diesel, biodiesel is a more sustainable and greener fuel. Vegetable oils such as soybean, canola, sunflower, palm, and rapeseed provide a renewable source of feedstock for the manufacturing of biodiesel. Sustainability problems like habitat degradation and deforestation make sustainable methods essential.

While leftover cooking oil can be recycled and reused to help create a circular economy and reduce carbon emissions, animal fats such as tallow and yellow grease can be used to manufacture biodiesel. Yeast and other oleaginous microorganisms like microalgae are becoming more and more popular as feedstocks for the manufacturing of biodiesel. Feedstocks include anaerobic digestion, municipal solid waste, and agricultural wastes. In an effort to increase sustainability and financial viability, hybrid feedstock approaches—such as crop residue integration, crop rotation plans, and waste cooking oil blends—are being researched. The lack of reactionary energy reserves in the transportation sector is driving up the need for energy in machinery.

Although biodiesel has benefits over petroleum diesel, it also has drawbacks, such as poor low-temperature performance and oxidative instability. Suitability needs to be determined through additional research programs for biofuels are essential for both profitable expansion and environmental impact, which affects terrain and food needs. The long-term effects depend on various factors, including population growth, climate change, technological advancements, and energy policies. By lowering greenhouse gas emissions, diversifying energy sources, and relying less on trade, biofuels can increase energy security, close the force-demand gap caused by oil poisoning, raise ranch income, and generate jobs. Liquid biofuels have the fastest rate of growth as a vital energy source. Biodiesel is a cleaner and renewable fuel substitute for traditional diesel, boosting economic growth across various industries. It addresses environmental issues, offers opportunities for regional and national economies, and improves energy security, balances the energy supply, and creates jobs. Biodiesel is carbon neutral, safer to handle, and less toxic than diesel. It can be recycled and biodegraded, making it a sustainable and viable alternative to conventional diesel. The biodiesel market is rapidly growing, with discussions about the economic benefits of using biomass in dry regions. However, glycerine production presents challenges due to water requirements. Biofuels produced with minimal energy input, on marginal land, and few other agricultural inputs could offer significant benefits. The most widely used process is alkaline transesterification, which turns vegetable or leftover cooking oils and animal fats into biodiesel. A systematic method for evaluating possible R&D pathways for biodiesel production is proposed, focusing on intrinsic safety, health, and environment (SHE) and economic performance (EP). Methods such as the Prototype Index of Inherent Safety (PIIS), the Inherent Occupational Health Index (IOHI), and the Inherent Environmental Toxicity Hazard (IETH) are used to perform inherent SHE assessments. In addition to making recommendations for modifying storage times, decreasing mass flows of recycled raw materials, minimizing waste disposal, switching from methanol to ethanol, avoiding harsh conditions, streamlining operational procedures, raising process yield, and using fewer chemicals, the study evaluates the intrinsic safety and health (SHE) of biodiesel production. The findings highlight the necessity of more research and development as well as the importance of evaluating SHE in the manufacture of biodiesel.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Vikas Srivastava, Assistant professor, Department of Applied Sciences (RRIMT) for providing the necessary information technology related resources to carry out the project.

 DOI : 10.35291/2454-9150.2024.0005

CONFLICT OF INTEREST

There is no conflict of interest among authors

REFRENCES

[1] Fulkerson W, Judkins RR, Sanghvi MK. Energy from fossil fuels. Scientific American. 1990 Sep 1;263(3):128-35.

[2] Asif M, Muneer T. Energy supply, its demand and security issues for developed and emerging economies. Renewable and sustainable energy reviews. 2007 Sep1;11(7):1388-413.

[3] Quadrelli R, Peterson S. The energy–climate challenge: Recent trends in CO2 emissions from fuel combustion. Energy policy. 2007 Nov 1;35(11):5938-52.

[4] Narasimharao K, Lee A, Wilson K. Catalysts in production of biodiesel: a review. Journal of biobased materials and bioenergy. 2007 Apr 1;1(1):19-30.

[5] Knothe G. Analyzing biodiesel: standards and other methods. Journal of the American Oil Chemists' Society. 2006 Oct;83(10):823-33.

[6] Tan HW, Aziz AA, Aroua MK. Glycerol production and its applications as a raw material: A review. Renewable and sustainable energy reviews. 2013 Nov1;27:118-27.

[7] Pullen J, Saeed K. An overview of biodiesel oxidation stability. Renewable and Sustainable Energy Reviews. 2012 Oct 1;16(8):5924-50.

[8] Aljaafari A, Fattah IM, Jahirul MI, Gu Y, Mahlia TM, Islam MA, Islam MS. Biodiesel emissions: A state-of-the-art review on health and environmental impacts. Energies. 2022 Sep 19;15(18):6854.

[9] Leung DY, Wu X, Leung MK. A review on biodiesel production using catalyzed transesterification. Applied energy. 2010 Apr 1;87(4):1083-95.

[10] Sundus F, Fazal MA, Masjuki HH. Tribology with biodiesel: A study on enhancing biodiesel stability and its fuel properties. Renewable and Sustainable Energy Reviews. 2017 Apr 1;70:399-412.

[11] Xu Y, Hellier P, Purton S, Baganz F, Ladommatos N. Algal biomass and diesel emulsions: An alternative approach for utilizing the energy content of microalgal biomass in diesel huengines. Applied Energy. 2016 Jun 15;172:80-95.

[12] Hasannuddin AK, Wira JY, Srithar R, Sarah S, Ahmad MI, Aizam SA, Aiman MA, Zahari M, Watanabe S, Azrin MA, Mohd SS. Effect of emulsion fuel on engine emissions–A review. Clean Technologies and Environmental Policy. 2016 Jan;18:17-32.

[13] Avagyan AB, Singh B, Avagyan AB, Singh B. Biodiesel from plant oil and waste cooking oil. Biodiesel: Feedstocks, Technologies, Economics and Barriers: Assessment of Environmental Impact in Producing and Using Chains. 2019:15-75.

[14] Yaakob Z, Mohammad M, Alherbawi M, Alam Z, Sopian K. Overview of the production of biodiesel from waste cooking oil. Renewable and sustainable energy reviews. 2013 Feb 1;18:184-93.

[15] Atadashi IM, Aroua MK, Aziz AA, Sulaiman NM. Production of biodiesel using high free fatty . Renewable and sustainable energy reviews. 2012 Jun 1;16(5):3275-85.

[16] Rashid U, Anwar F. Production of biodiesel through optimized alkaline-catalyzed transesterification of rapeseed oil. Fuel. 2008 Mar 1;87(3):265-73.

[17] Dash SK, Lingfa P. A review on production of biodiesel using catalyzed transesterification. InAIP conference proceedings 2017 Jul 19 (Vol. 1859, No. 1). AIP Publishing.

[18] savi D, Zhou H, Lin L. Biodiesel: an alternative to conventional fuel. Energy Procedia. 2012 Jan 1;16:1874-85.

[19] Bates A, Draper K. Burn: Igniting a New Carbon Drawdown Economy to End theClimate Crisis. Chelsea Green Publishing; 2020 Apr 14.

[20] Demirbas A. Biofuels securing the planet's future energy needs. Energy conversion and management. 2009 Sep 1;50(9):2239-49.

[21] Hoang AT, Sirohi R, Pandey A, Nižetić S, Lam SS, Chen WH, Luque R, Thomas S, Arıcı M, Pham VV. Biofuel production from microalgae: challenges and chances. Phytochemistry Reviews. 2023 Aug;22(4):1089-126.

[22] Luque R, Lovett JC, Datta B, Clancy J, Campelo JM, Romero AA. Biodiesel as feasible petrol fuel replacement: a multidisciplinary overview. Energy & Environmental Science. 2010;3(11):1706-21.

[23] Saville BA, Villeneuve S. Economic impact study for a canola-based biodiesel industry in Canada. Canola Council of Canada; 2006 Jul.

[24] Lim S, Teong LK. Recent trends, opportunities and challenges of biodiesel in Malaysia: an overview. Renewable and Sustainable Energy Reviews. 2010 Apr1;14(3):938-54.

[25] Shirvani T, Yan X, Inderwildi OR, Edwards PP, King DA. Life cycle energy and greenhouse gas analysis for algae-derived biodiesel. Energy & Environmental Science. 2011;4(10):3773-8.

[26] Chen R, Qin Z, Han J, Wang M, Taheripour F, Tyner W, O'Connor D, Duffield J. Life cycle energy and greenhouse gas emission effects of biodiesel in the United States with induced land use change impacts. Bioresource technology. 2018 Mar 1;251:249-58.

[27] He BQ. Advances in emission characteristics of diesel engines using different biodiesel fuels. Renewable and Sustainable Energy Reviews. 2016 Jul 1;60:570-86.

[28] Haruna A, Merican ZM, Musa SG, Abubakar S. Sulfur removal technologies from fuel oil for safe and sustainable environment. Fuel. 2022 Dec 1;329:125370.

[29] Demirbas A. Comparison of transesterification methods for production of biodiesel from vegetable oils and fats. Energy conversion and management. 2008 Jan 1;49(1):125-30.

[30] Rodrigues A, Bordado JC, Galhano dos Santos R. Upgrading the glycerol from biodiesel production as a source of energy carriers and chemicals—A technological review for three chemical pathways. Energies. 2017 Nov 9;10(11):1817.

[31] Shiozawa S, Meirelles AJ, Batista EA. Liquid–liquid equilibrium data for systems important in biodiesel production, involving vegetable oils+ ethyl esters+ monoacylglycerols and diacylglycerols+ anhydrous ethanol, at 303.15 and 318.15 K. Fuel. 2016 Sep 15;180:332-42.

[32] Dupont J, Suarez PA, Meneghetti MR, Meneghetti SM. Catalytic production of biodiesel and diesel-like hydrocarbons from triglycerides. Energy & Environmental Science. 2009;2(12):1258-65.

[33] Singh B, Guldhe A, Rawat I, Bux F. Towards a sustainable approach for development of biodiesel from plant and microalgae. Renewable and sustainableEnergy reviews. 2014 Jan 1;29:216-45.

[34] Shaah MA, Hossain MS, Allafi FA, Alsaedi A, Ismail N, Ab Kadir MO, Ahmad MI. A review on non-edible oil as a potential feedstock for biodiesel: physicochemical properties and production technologies. RSC advances. 2021;11(40):25018-37.

[35] Ma F, Hanna MA. Biodiesel production: a review. Bioresource technology. 1999 Oct1;70(1):1-5.

[36] Butler E, Devlin G, Meier D, McDonnell K. A review of recent laboratory research and commercial developments in fast pyrolysis and upgrading. Renewable and sustainable energy reviews. 2011 Oct 1;15(8):4171-86.

[37] Malabadi RB, Sadiya MR, Kolkar KP, Chalannavar RK. Biodiesel production via transesterification reaction.

[38] Feddern V, Junior AC, De Prá MC, De Abreu PG, dos Santos Filho JI, Higarashi MM, Sulenta M, Coldebella A. Animal fat wastes for biodiesel production.Biodiesel-feedstocks and processing technologies. 2011 Nov 9;45.

[39] Helwani Z, Othman MR, Aziz N, Kim J, Fernando WJ. Solid heterogeneous catalysts for transesterification of triglycerides with methanol: a review. Applied Catalysis A: General. 2009 Jul 1;363(1-2):1-0.

[40] Tan HW, Aziz AA, Aroua MK. Glycerol production and its applications as a raw material: A review. Renewable and sustainable energy reviews. 2013 Nov 1;27:118-27.

 DOI : 10.35291/2454-9150.2024.0005

[41] Yaashikaa PR, Kumar PS, Karishma S. Bio-derived catalysts for production of biodiesel: A review on feedstock, oil extraction methodologies, reactors and lifecycle assessment of biodiesel. Fuel. 2022 May 15;316:123379.

[42] Narasimharao K, Lee A, Wilson K. Catalysts in production of biodiesel: a review. Journal of biobased materials and bioenergy. 2007 Apr 1;1(1):19-30.

[43] Okonkwo CP, Ajiwe VI, Obiadi MC, Okwu M. A Systematic Review of Biodiesel Production with Sustainable Feedstock Using Assorted Catalyst. American Journal of Applied Chemistry. 2021;9(5):154-63.

[44] Cetinkaya M, Karaosmanoğlu F. Optimization of base-catalyzed transesterification reaction of used cooking oil. Energy & fuels. 2004 Nov 17;18(6):1888-95.

[45] Christopher LP, Kumar H, Zambare VP. Enzymatic biodiesel: Challenges and opportunities. Applied Energy. 2014 Apr 15;119:497-520.

[46] Severo IA, Siqueira SF, Depra MC, Maroneze MM, Zepka LQ, Jacob-Lopes E. Biodiesel facilities: What can we address to make biorefineries commercially competitive?. Renewable and Sustainable Energy Reviews. 2019 Sep 1;112:686-705.

[47] Salaheldeen M, Mariod AA, Aroua MK, Rahman SA, Soudagar ME, Fattah IR. Current state and perspectives on transesterification of triglycerides for biodiesel production. Catalysts. 2021 Sep 18;11(9):1121.

[48] Gürsel IV, Hessel V, Wang Q, Noël T, Lang J. Window of opportunity–potential of increase in profitability using modular compact plants and micro-reactor based flow processing. Green Processing and Synthesis. 2012 Aug 1;1(4):315-36.

[49] Lusas EW, Alam MS, Clough RC, Riaz MN. Animal and vegetable fats, oils, and waxes. InHandbook of Industrial Chemistry and Biotechnology 2012 Nov 19 (pp. 1323-1402). Boston, MA: Springer US.

[50] You YD, Shie JL, Chang CY, Huang SH, Pai CY, Yu YH, Chang CH. Economic cost analysis of biodiesel production: case in soybean oil. Energy & Fuels. 2008 Jan 16;22(1):182-9.

[51] Salaheldeen M, Mariod AA, Aroua MK, Rahman SA, Soudagar ME, Fattah IR. Current state and perspectives on transesterification of triglycerides for biodiesel production. Catalysts. 2021 Sep 18;11(9):1121.

[52] Amann M, Bertok I, Borken-Kleefeld J, Cofala J, Heyes C, Höglund-Isaksson L, Klimont Z, Nguyen B, Posch M, Rafaj P, Sandler R. Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. Environmental Modelling & Software. 2011 Dec 1;26(12):1489-501

[53] Gasparatos A, Romeu-Dalmau C, von Maltitz GP, Johnson FX, Shackleton C, Jarzebski MP, Jumbe C, Ochieng C, Mudombi S, Nyambane A, Willis KJ. Mechanisms and indicators for assessing the impact of biofuel feedstock production on ecosystem services. Biomass and Bioenergy. 2018 Jul 1;114:157-73.

[54] Duflou JR, Sutherland JW, Dornfeld D, Herrmann C, Jeswiet J, Kara S, Hauschild M, Kellens K. Towards energy and resource efficient manufacturing: A processes and systems approach. CIRP annals. 2012 Jan 1;61(2):587-609.

[55] Arshad M, Abbas M. Water sustainability issues in biofuel production. Perspectives on Water Usage for Biofuels Production: Aquatic Contamination and Climate Change. 2018:55-76.

[56] Singh D, Sharma D, Soni SL, Sharma S, Sharma PK, Jhalani A. A review on feedstocks, production processes, and yield for different generations of biodiesel. Fuel. 2020 Feb 15;262:116553.

[57] Singh d SP, Seabra JE, Nogueira LA. Feedstocks for biodiesel production: Brazilian and global perspectives. Biofuels. 2018 Jul 4;9(4):455-78

[58] Lewandowski I, Faaij AP. Steps towards the development of a certification system for sustainable bio-energy trade. Biomass and Bioenergy. 2006 Feb 1;30(2):83-104.

[59] Ikram MM, Hanif MA, Khan GS, Rashid U, Nadeem F. Significant seed oil feedstocks for renewable production of biodiesel: a review. Current Organic Chemistry. 2019 Jun 1;23(14):1509-16.

[60] Eynck C, Shrestha D, Vollmann J, Falk KC, Friedt W, Singh HP, Obeng E. Sustainable oil crops production. Biofuel Crop Sustainability. 2013 May 12:165-204.

[61] Sheil D, Casson A, Meijaard E, Van Noordwijk M, Gaskell J, Sunderland-Groves J, Wertz K, Kanninen M. The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?. Bogor, Indonesia: Center for International Forestry Research; 2009.

[62] Feddern V, Junior AC, De Prá MC, De Abreu PG, dos Santos Filho JI, Higarashi MM, Sulenta M, Coldebella A. Animal fat wastes for biodiesel production.

[63] Biodiesel-feedstocks and processing technologies. 2011 Nov 9;45.

[64] Demirbas A. Political, economic and environmental impacts of biofuels: A review. Applied energy. 2009 Nov 1;86:S108-17.

[65] Yaakob Z, Mohammad M, Alherbawi M, Alam Z, Sopian K. Overview of the production of biodiesel from waste cooking oil. Renewable and sustainable energy reviews. 2013 Feb 1;18:184-93.

[66] Radakovits R, Jinkerson RE, Darzins A, Posewitz MC. Genetic engineering of algae for enhanced biofuel production. Eukaryotic cell. 2010 Apr;9(4):486-501.

[67] Kendrick M. Algal bioreactors for nutrient removal and biomass production during the tertiary treatment of domestic sewage (Doctoral dissertation, Loughborough University).

[68] Chandra R, Takeuchi H, Hasegawa T. Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. Renewable and Sustainable Energy Reviews. 2012 Apr 1;16(3):1462-76.

[69] Ohnishi S, Fujii M, Ohata M, Rokuta I, Fujita T. Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city. Resources, Conservation and Recycling. 2018 Jan 1;128:394-405.

[70] Brahma S, Nath B, Basumatary B, Das B, Saikia P, Patir K, Basumatary S. Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production. Chemical Engineering Journal Advances. 2022 May 15;10:100284.

[71] Dwivedi G, Jain S, Sharma MP. Impact analysis of biodiesel on engine performance—A review. Renewable and Sustainable Energy Reviews. 2011 Dec 1;15(9):4633-41.

[72] Narasimharao K, Lee A, Wilson K. Catalysts in production of biodiesel: a review. Journal of biobased materials and bioenergy. 2007 Apr 1;1(1):19-30.

[73] Mahmudul HM, Hagos FY, Mamat R, Adam AA, Ishak WF, Alenezi R. Production, characterization and performance of biodiesel as an alternative fuel in diesel engines–A review. Renewable and Sustainable Energy Reviews. 2017 May 1;72:497-509.

[74] Gheewala SH, Damen B, Shi X. Biofuels: economic, environmental and social benefits and costs for developing countries in Asia. Wiley Interdisciplinary Reviews: Climate Change. 2013 Nov;4(6):497-511.

[75] Nigam PS, Singh A. Production of liquid biofuels from renewable resources. Progress in energy and combustion science. 2011 Feb 1;37(1):52-68.

[76] Avagyan AB, Singh B. Biodiesel: feedstocks, technologies, economics and barriers. Assessment of Environmental Impact in Producing and Using Chains. Assessment of Environmental Impact in Producing and Using Chains. 2019.

[77] Puricelli S, Cardellini G, Casadei S, Faedo D, Van den Oever AE, Grosso M. A review on biofuels for light-duty vehicles in Europe. Renewable and Sustainable Energy Reviews. 2021 Mar 1;137:110398.

[78] Agarwal AK, Gupta JG, Dhar A. Potential and challenges for large-scale application of biodiesel in automotive sector. Progress in Energy and Combustion Science. 2017 Jul 1;61:113-49.

 DOI : 10.35291/2454-9150.2024.0005

[79] Mwangi JK, Lee WJ, Chang YC, Chen CY, Wang LC. An overview: Energy saving and pollution reduction by using green fuel blends in diesel engines. Applied Energy. 2015 Dec 1;159:214-36.

[80] Lund PD, Lindgren J, Mikkola J, Salpakari J. Review of energy system flexibility measures to enable high levels of variable renewable electricity. Renewable and sustainable energy reviews. 2015 May 1;45:785-807.

[81] Easmin F, Rahman AM. Production of Biodiesel from Algae by Trans-esterification.

[82] Pickthall B. Reeds Diesel Engine Troubleshooting Handbook. Bloomsbury Publishing; 2012 Dec 27.

[83] Dingwall R, Balmer A, Goulden M. BBSRC sustainable bioenergy scenario tool. UK: BBSRC. 2011 Aug 1.

[84] Chandran D. Experimental investigation into the physico-chemical properties changes of palm biodiesel under common rail diesel engine operation for the elucidation of metal corrosion and elastomer degradation in fuel delivery system (Doctoral dissertation, University of Nottingham).

[85] Kuppusamy S, Maddela NR, Megharaj M, Venkateswarlu K, Kuppusamy S, Maddela NR, Megharaj M, Venkateswarlu K. An overview of total petroleum hydrocarbons. Total Petroleum Hydrocarbons: Environmental Fate, Toxicity, and Remediation. 2020:1-27.

[86] Zhang X, Pan L, Wang L, Zou JJ. Review on synthesis and properties of high-energy-density liquid fuels: Hydrocarbons, nanofluids and energetic ionic liquids. Chemical Engineering Science. 2018 Apr 28;180:95-125.

[87] Aydın H, İlkılıç C. Analysis of combustion, performance and emission characteristics of a diesel engine using low sulfur tire fuel. Fuel. 2015 Mar 1;143:373-82.

[88] Song C. An overview of new approaches to deep desulfurization for ultra-clean gasoline, diesel fuel and jet fuel. Catalysis today. 2003 Nov 1;86(1-4):211-63.

[89] Santana RC, Do PT, Santikunaporn M, Alvarez WE, Taylor JD, Sughrue EL, Resasco DE. Evaluation of different reaction strategies for the improvement of cetane number in diesel fuels. Fuel. 2006 Mar 1;85(5-6):643-56.

[90] Fayyazbakhsh A, Bell ML, Zhu X, Mei X, Koutný M, Hajinajaf N, Zhang Y. Engine emissions with air pollutants and greenhouse gases and their control technologies. Journal of Cleaner Production. 2022 Sep 22:134260.

[91] Tran VD, Le AT, Hoang AT. An experimental study on the performance characteristics of a diesel engine fueled with ULSD-biodiesel blends. International Journal of Renewable Energy Development. 2021 May 1;10(2):183.

[92] Abdul Raman AA, Tan HW, Buthiyappan A. Two-step purification of glycerol as a value added by product from the biodiesel production process. Frontiers in chemistry. 2019 Nov 19;7:774.

[93] Hoang AT, Nižetić S, Ong HC, Tarelko W, Le TH, Chau MQ, Nguyen XP. A review on application of artificial neural network (ANN) for performance and emission characteristics of diesel engine fueled with biodiesel-based fuels. Sustainable Energy Technologies and Assessments. 2021 Oct 1;47:101416.

[94] Sinha SK, Gupta A, Bharalee R. Production of biodiesel from freshwater microalgae and evaluation of fuel properties based on fatty acid methyl ester profile. Biofuels. 2016 Jan 2;7(1):69-78.

[95] Gülüm M, Bilgin A. Density, flash point and heating value variations of corn oil biodiesel–diesel fuel blends. Fuel Processing Technology. 2015 Jun 1;134:456-64.

[96] Asikin-Mijan N, Juan JC, Taufiq-Yap YH, Ong HC, Lin YC, AbdulKareem-Alsultan G, Lee HV. Towards sustainable green diesel fuel production: Advancements and opportunities in acid-base catalyzed H2-free deoxygenation process. Catalysis Communications. 2023 Sep 1;182:106741.

[97] Kuppusamy S, Maddela NR, Megharaj M, Venkateswarlu K, Kuppusamy S, Maddela NR, Megharaj M, Venkateswarlu K. An overview of total petroleum hydrocarbons. Total Petroleum Hydrocarbons: Environmental Fate, Toxicity, and Remediation. 2020:1-27.

[98] Knothe G, Matheaus AC, Ryan III TW. Cetane numbers of branched and straight-chain fatty esters determined in an ignition quality tester☆. Fuel. 2003 May 1;82(8):971-5.

[99] Matzke M, Jess A, Litzow U. Polar nitrogen-containing aromatic compounds as carriers of natural diesel lubricity. Fuel. 2015 Jan 15;140:770-7.

[100] Clark CM, Lin Y, Bierwagen BG, Eaton LM, Langholtz MH, Morefield PE, Ridley CE, Vimmerstedt L, Peterson S, Bush BW. Growing a sustainable biofuels industry: economics, environmental considerations, and the role of the Conservation Reserve Program. Environmental Research Letters. 2013 May15;8(2):025016.

[101] Chapman SC, Chakraborty S, Dreccer MF, Howden SM. Plant adaptation to climate change—opportunities and priorities in breeding. Crop and Pasture Science. 2012 May 28;63(3):251-68.

[102] Altenburg T, Dietz H, Hahl M, Nikolidakis N, Rosendahl C, Seelige K. Biodiesel policies for rural development in India. German Development Institute. 2008 May.

[103] Plevin RJ, Jones AD, Torn MS, Gibbs HK. Greenhouse gas emissions from biofuels' indirect land use change are uncertain but may be much greater than previously estimated.

[104] Jensen ES, Peoples MB, Boddey RM, Gresshoff PM, Hauggaard-Nielsen H, JR Alves B, Morrison MJ. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agronomy for sustainable development. 2012 Apr;32:329-64.

[105] Malode SJ, Gaddi SA, Kamble PJ, Nalwad AA, Muddapur UM, Shetti NP. Recent evolutionary trends in the production of biofuels. Materials Science for Energy Technologies. 2022 Jan 1;5:262-77.

[106] Shahare VV, Kumar B, Singh P. Biofuels for sustainable development: a global perspective. Green technologies and environmental sustainability. 2017:67-89.

[107] Balasubramanian N, Steward KF. Biodiesel: history of plant based oil usage and modern innovations. Substantia. 2019 Sep;3(2):57-71.

[108] Hirsch RL, Bezdek R, Wendling R. Peaking of world oil production: impacts, mitigation, & risk management. National Energy Technology Laboratory (NETL), Pittsburgh, PA, Morgantown, WV, and Albany, OR; 2005 Feb 1.

[109] Christopher LP, Kumar H, Zambare VP. Enzymatic biodiesel: Challenges and opportunities. Applied Energy. 2014 Apr 15;119:497-520.

[110] Forster J, Vaughan NE, Gough C, Lorenzoni I, Chilvers J. Mapping feasibilities of greenhouse gas removal: key issues, gaps and opening up assessments. Global Environmental Change. 2020 Jul 1;63:102073.

[111] Raheem A, Prinsen P, Vuppaladadiyam AK, Zhao M, Luque R. A review on sustainable microalgae based biofuel and bioenergy production: Recent developments. Journal of cleaner production. 2018 Apr 20;181:42-59.

[112] Williams PJ, Laurens LM. Microalgae as biodiesel & biomass feedstocks: Review & analysis of the biochemistry, energetics & economics. Energy & environmental science. 2010;3(5):554-90.

[113] Stančin H, Mikulčić H, Wang X, Duić N. A review on alternative fuels in future energy system. Renewable and sustainable energy reviews. 2020 Aug 1;128:109927.

[114] Klymchuk O, Khodakivska O, Kovalov B, Brusina A, Benetyte R, Momotenko I. World trends in bioethanol and biodiesel production in the context of sustainable energy development. International Journal of Global Environmental Issues.2020;19(1-3):90-108.

[115] Sivakumar G, Vail DR, Xu J, Burner DM, Lay JO, Ge X, Weathers PJ. Bioethanol and biodiesel: Alternative liquid fuels for future generations. Engineering in Life Sciences. 2010 Feb;10(1):8-18.

[116] Laney K. Biofuels: Promises and constraints. IN: IPC DISCUSSION PAPER DECEMBER. 2006 Dec 17.

 DOI : 10.35291/2454-9150.2024.0005

[117] Demirbas A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energy conversion and management. 2008 Aug 1;49(8):2106-16.

[118] Huang D, Zhou H, Lin L. Biodiesel: an alternative to conventional fuel. Energy Procedia. 2012 Jan 1;16:1874-85.

[119] Negash M, Riera O. Biodiesel value chain and access to energy in Ethiopia: Policies and business prospects. Renewable and Sustainable Energy Reviews. 2014 Nov 1;39:975-85.

[120] Abedin MJ, Masjuki HH, Kalam MA, Sanjid A, Rahman SA, Masum BM. Energy balance of internal combustion engines using alternative fuels. Renewable and Sustainable Energy Reviews. 2013 Oct 1;26:20-33.Elsayed MA, Matthews R, Mortimer ND. Carbon and energy balances for a range of biofuels options.

[121] Khan N, Sudhakar K, Mamat R. Role of biofuels in energy transition, green economy and carbon neutrality. Sustainability. 2021 Nov 9;13(22):12374.

[122] Živković S, Veljković M. Environmental impacts the of production and use of biodiesel. Environmental Science and Pollution Research. 2018 Jan;25:191-9.

[123] Agarwal AK. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in energy and combustion science. 2007 Jun1;33(3):233-71.

[124] Balat M. Potential alternatives to edible oils for biodiesel production–A review of current work. Energy conversion and management. 2011 Feb 1;52(2):1479-92.

[125] Olah GA, Prakash GS, Goeppert A. Anthropogenic chemical carbon cycle for a sustainable future. Journal of the American Chemical Society. 2011 Aug24;133(33):12881-98.

[126] Le TT, Sharma P, Bora BJ, Tran VD, Truong TH, Le HC, Nguyen PQ. Fueling the future: A comprehensive review of hydrogen energy systems and their challenges. International Journal of Hydrogen Energy. 2023 Aug 19.

[127] Timilsina GR, Shrestha A. How much hope should we have for biofuels?. Energy. 2011 Apr 1;36(4):2055-69.

[128] Popp J, Harangi-Rákos M, Gabnai Z, Balogh P, Antal G, Bai A. Biofuels and their co-products as livestock feed: global economic and environmental implications. Molecules. 2016 Feb 29;21(3):285.

[129] Scheffran J. The global demand for biofuels: technologies, markets and policies. Biomass to biofuels: strategies for global industries. 2010 Jan 15:27-54.

[130] Gebremariam SN, Marchetti JM. Economics of biodiesel production. Energy Conversion and Management. 2018 Jul 15;168:74-84.

[131] Nanda S, Rana R, Sarangi PK, Dalai AK, Kozinski JA. A broad introduction to first-, second-, and third-generation biofuels. Recent advancements in biofuels and bioenergy utilization. 2018:1-25.

[132] Demirbas A. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. Progress in energy and combustion science. 2005 Jan 1;31(2):171-92.

[133] DEMİRBAŞ A. Biodiesel impacts on compression ignition engine (CIE): Analysis of air pollution issues relating to exhaust emissions. Energy Sources. 2005 Mar 23;27(6):549-58.

[134] Atabani AE, Silitonga AS, Ong HC, Mahlia TM, Masjuki HH, Badruddin IA, Fayaz H. Non-edible vegetable oils: a critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. Renewable and sustainable energy reviews. 2013 Feb 1;18:211-45.

[135] Khan IU, Long H, Yu Y. Potential and comparative studies of six non-edible seed oil feedstock's for biodiesel production. International Journal of Green Energy. 2023 Jun 11:1-21.

[136] Taha M, Foda M, Shahsavari E, Aburto-Medina A, Adetutu E, Ball A. Commercial feasibility of lignocellulose biodegradation: possibilities and challenges. Current Opinion in Biotechnology. 2016 Apr 1;38:190-7.

[137] Brown KL. The economic feasibility of utilizing energy cane in the cellulosic production of ethanol. Louisiana State University and Agricultural & Mechanical College; 2012.

[138] Lin L, Cunshan Z, Vittayapadung S, Xiangqian S, Mingdong D. Opportunities and challenges for biodiesel fuel. Applied energy. 2011 Apr 1;88(4):1020-31.

[139] Dou B, Song Y, Wang C, Chen H, Xu Y. Hydrogen production from catalytic steam reforming of biodiesel byproduct glycerol: Issues and challenges. Renewable and Sustainable Energy Reviews. 2014 Feb 1;30:950-60.

[140] Lampert DJ, Cai H, Elgowainy A. Wells to wheels: water consumption for transportation fuels in the United States. Energy & Environmental Science. 2016;9(3):787-802.

[141] Li Y, Zhang XD, Sun L. Fatty acid methyl esters from soapstocks with potential use as biodiesel. Energy Conversion and Management. 2010 Nov 1;51(11):2307-11.

[142] Yusoff MF, Xu X, Guo Z. Comparison of fatty acid methyl and ethyl esters as biodiesel base stock: a review on processing and production requirements. Journal of the American Oil Chemists' Society. 2014 Apr;91:525-31.

[143] Quina MJ, Bontempi E, Bogush A, Schlumberger S, Weibel G, Braga R, Funari V, Hyks J, Rasmussen E, Lederer J. Technologies for the management of MSW incineration ashes from gas cleaning: New perspectives on recovery of secondary raw materials and circular economy. Science of the total environment. 2018 Sep 1;635:526-42.

[144] Ruhul AM, Kalam MA, Masjuki HH, Fattah IR, Reham SS, Rashed MM. State of the art of biodiesel production processes: a review of the heterogeneous catalyst. RSC Advances.2015;5(122)

 DOI : 10.35291/2454-9150.2024.0005