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Biodiesel: The fuel of future

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Abstract
The manufacturing of biodiesel has seen some major advances in recent years that attempt to improve environmental performance, sustainability, and efficiency. The research of non-food sources like algae, jatropha, and waste oils has been encouraged by a significant trend called feedstock diversification. Enzymatic and supercritical fluid transesterification are two advanced manufacturing techniques that have showed promise in increasing conversion rates and processing a larger variety of feedstocks. Demand has increased and production has been encouraged by regulatory and blending programmes, such as mandating biodiesel use and blending biodiesel with petroleum fuel. The emphasis now is on sustainability and carbon reduction, with certification programmes ensuring compliance with social and environmental standards.

Keywords: Feedstock diversification, enzymatic transesterification, supercritical fluid transesterification, sustainability, carbon reduction, nanotechnology

Introduction
Global total primary energy consumption (TPEC) has significantly increased as a result of population growth, rapid urbanisation, and industrialization. This has increased greenhouse gas (GHG) emissions, acid rain, and global warming, all of which pose serious environmental threats (Singh *et al*., 2019) [13]. Fossil fuels, which are non-renewable and quickly depleting, have been used as the main energy sources to meet the expanding demand (Hajjari *et al*., 2017) [6].

Fossil fuel combustion results in significant emissions of CO_2, a well-known greenhouse gas and a key contributor to global climate change. Since 1990, the average global temperature has increased by 1-1.2 °C due to an increase in CO_2 concentration from 369.38 parts per million in 2000 to 417.53 parts per million in 2022 (https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions). It is obvious that considerable adjustments to the current energy systems and their effects on the environment are needed to stop the imminent collapse of the biosphere. The creation of alternative, renewable, and economically viable energy sources is therefore urgently needed (Qadeer *et al*., 2021) [10].

A promising possibility in the search for alternative fuels has emerged: biodiesel. It is a biodegradable, renewable, non-toxic, and environmentally benign fuel that burns without producing a lot of sulphates or aromatic hydrocarbons. The essential starting components for the production of biodiesel are widely accessible and often inexpensive. Biodiesel is described as "a fuel composed of mono-alkyl esters of long-chain fatty acids, derived from renewable vegetable oils or animal fats, meeting the requirements of ASTM D6751" (Mishra and Goswami, 2018; Qadeer *et al*., 2021) [7, 10]. This definition comes from the American Society for Testing and Materials, International (ASTM International).

The cost of producing biodiesel now prevents many countries, including the United States, the world's largest producer, from making it economically feasible. In the US, Brazil, and Argentina, soybean oil is the main raw material used to make biodiesel, although its oil output is just 18%. Genetic engineering methods are being used to boost soybean yields and oil content in order to remedy this. Rapeseed is a significant biodiesel feedstock in Europe, which drives up production costs even more when compared to other regions.

The cost of producing biodiesel now prevents many countries, including the United States, the world's largest producer, from making it economically feasible. Although soybean oil has a poor oil yield, it is the main raw material used to make biodiesel in the United States, Brazil, and Argentina.

India has paid a lot of attention to producing and using biodiesel as it works to lessen its reliance on fossil fuels, address environmental issues, and encourage renewable energy sources. A variety of oilseed crops, including *Jatropha*, *Pongamia*, *Mahua*, and *Karanja*, which are suitable for biodiesel production due to their high oil content, are among the abundant resources available in India for the manufacture of biodiesel (Demirbas, 2009; Rizwanul Fattah *et al*., 2018) [2, 11, 12].

The selection of affordable feedstocks is the first step in this article's thorough analysis of techniques that can enhance many elements of biodiesel synthesis. The economics and sustainability of biodiesel production can be improved by increasing the lipid content in specific feedstocks using molecular biology, genetic engineering, and enhanced oil extraction processes.

Selection of Feed Stock

The selection of feedstock is influenced by a number of variables, including accessibility, price, oil content, sustainability, and regional agricultural practises. Depending on the temperature and agricultural conditions, certain feedstocks may be more suited in a certain place.

It's crucial to check that the feedstock chosen for the manufacture of biodiesel is environmentally friendly, sustainable, and does not compete with food production. The ultimate qualities of the biodiesel fuel and the biodiesel production process can both be influenced by the quality and content of the feedstock.

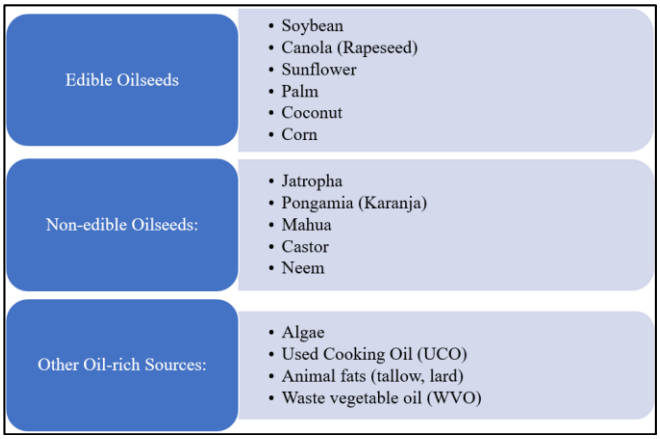

Fig 1: Feedstocks for biodiesel production

Sustainability is essential since it guarantees that the feedstock has no adverse environmental effects, such as deforestation or land degradation. Feedstocks that compete with the production of food must also be avoided since they can cause food insecurity or raise food prices.

Additionally, the characteristics of the final biodiesel fuel are greatly influenced by the quality and content of the feedstock during the production process. To achieve effective conversion into biodiesel, the feedstock should have a proper fatty acid composition and minimal amounts of contaminants, such as free fatty acids and moisture. Additionally, the characteristics of the final biodiesel fuel are greatly influenced by the quality and content of the feedstock during the production process. To achieve effective conversion into biodiesel, the feedstock should have a proper fatty acid composition and minimal amounts of contaminants, such as free fatty acids and moisture. According to the local climate, agricultural potential, and economic considerations, certain geographical areas around the world have particular feedstocks that are more suited. It is crucial for each region to assess and choose the best feedstock that satisfies their unique needs. The biodiesel business can assure sustainable and ecologically friendly production while supporting the worldwide shift to renewable energy sources by taking these issues into account and making educated decisions (Patel *et al*., 2020; Rizwanul Fattah *et al*., 2018) [8, 9, 11, 12].

Strategies to enhance biodiesel production

To improve biodiesel production and make it more effective and profitable, a number of strategies can be used (Mishra and Goswami, 2018; Qadeer *et al*., 2021) [7, 10]. These strategies include, among others:

Choice of Feedstock: Choosing the correct feedstock is essential for the manufacturing of biodiesel. The goal of research is to find high-yielding feedstocks with the best composition and oil content. This entails looking into waste oils, algae, and non-food oilseeds as potential feedstocks.

Genetic Engineering: The oil content and quality of feedstocks can be improved through genetic engineering approaches. This entails manipulating plant metabolic pathways to boost oil production or changing the fatty acid composition to enhance the qualities of biodiesel.

Advanced Extraction Methods: It is critical to develop effective and affordable strategies for extracting oil from feedstocks. Modern extraction methods can increase oil recovery and use less energy, such as supercritical fluid extraction, enzymatic extraction, and ultrasound-assisted extraction.

Process improvement: Increasing the efficiency of the transesterification process, which turns oil into biodiesel, can increase conversion rates. For optimal biodiesel yield, variables like temperature, catalyst type and concentration, alcohol-to-oil ratio, and reaction time need to be optimised.

Catalyst Development: Research for the transesterification reaction is focused on creating new catalysts or optimising those that already exist. In order to speed up the reaction and raise the calibre of the resulting biodiesel, catalysts are essential. Research is now being done on heterogeneous catalysts, enzyme catalysts, and nanocatalysts.

Utilisation of Co-Products: Investigating value-added uses for co-products produced during the manufacturing of biodiesel can improve the overall process economy. Co-products like glycerol can either be used as a feedstock for other businesses or processed further to provide valuable chemicals.

Sustainability Assessment: It is crucial to carry out thorough sustainability analyses to determine how producing biodiesel would affect the environment, society, and economy. To ensure the overall sustainability of biodiesel production, this includes evaluating variables including land use, water use, energy input, and greenhouse gas emissions.

The production of biodiesel can be improved, making it a more sustainable and financially viable alternative to fossil

fuels, with the help of these strategies and ongoing research and development activities.

Applications of Biodiesel

As a renewable and environmentally beneficial fuel, biodiesel has many uses across numerous industries (Knothe, G. 2018; Rizwanul Fattah *et al*., 2018) [5, 11, 12]. Among the most important uses for biodiesel are:

Transportation: In transportation vehicles including cars, trucks, buses, and trains, biodiesel can be used as a direct replacement or blended with regular diesel fuel. It is a practical alternative fuel choice because it can be utilised in existing diesel engines without the need for significant modifications. Many nations regularly utilise biodiesel blends like B20 (20% biodiesel and 80% diesel).

Aviation: The aviation industry can use biodiesel as a sustainable aviation fuel (SAF). Jet fuels made from biodiesel, or "bio-jet fuels," can be substituted directly for or combined with regular jet fuel. SAFs contribute to bettering the sustainability of air travel by lowering greenhouse gas emissions.

Agriculture & Construction Equipment: Off-road vehicles, construction equipment, and other machinery can all be powered by biodiesel. Because of its use in various fields, carbon emissions are decreased, making the environment cleaner and greener.

Power generation: In distant or off-grid regions, biodiesel can be used in diesel generators to generate electricity. It offers a decentralised power generation alternative that uses renewable energy.

Marine Applications: Marine vessels such as ferries, ships, and boats can run on biodiesel as a fuel. Its application in the maritime sector aids in lowering water pollution and carbon emissions.

Applications for Heating and Residential Buildings: Both commercial and residential buildings can utilise biodiesel for heating purposes. It is a sustainable and cleaner heating option that may be employed in oil-fired boilers and furnaces.

Applications in Industry: Biodiesel can be used as a fuel for a variety of industrial operations, including heating, processing, and manufacturing. It can take the place of conventional fossil fuels, reducing emissions and the impact on the environment.

A blend of biodiesel can be utilised in bio-based lubricants, solvents, and other chemical products in addition to these uses. Biodiesel is a competitive alternative to fossil fuels in many industries because to its adaptability and compatibility with current infrastructure and engines.

Economic Viability of Biodiesel in India

The practicality and mass acceptance of biodiesel in India are greatly influenced by its economic features. The economics of biodiesel production and use in the nation are influenced by a number of factors.

Cost of Feedstock: A crucial factor in the economics of biodiesel production is the cost of feedstock. The overall cost of production is influenced by the accessibility and cost of acceptable feedstock, such as waste oils or oilseeds. Due to their availability and appropriateness for the manufacturing of biodiesel, non-edible oilseeds like *Jatropha* and *Pongamia* have been thought of as viable feedstocks in India (Patel & Sharma, 2020) [8, 9]. To guarantee the financial viability of biodiesel production, cost-effective feedstock must be purchased and grown.

Production Volume: The economics of biodiesel production are also impacted by its volume. Large-scale manufacturing facilities gain. Economies of scale are advantageous for large-scale production facilities because they can lower production costs. Cost reductions and better economic viability might result from raising the production capacity and improving the manufacturing procedures (Joshi *et al*., 2014) [4].

Government Support and Incentives: In India, the economic benefits of biodiesel are greatly influenced by the government's support and incentives. Government measures like the Biodiesel Purchase Policy, which requires the blending of biodiesel with diesel and establishes a market for biodiesel, have been put into place (Joshi *et al*., 2014) [4]. To promote biodiesel production and the construction of biodiesel facilities, financial incentives, tax advantages, and subsidies are also offered (Rizwanul Fattah *et al*., 2018) [11, 12].

Blending biodiesel and market demand: The market's demand for biodiesel and the government's blending requirements have an impact on India's economic prospects for the fuel. By mixing biodiesel with diesel, a market is created and its use is guaranteed. Biodiesel producers may have better economic possibilities as market demand for the fuel rises.

Cost of Infrastructure and Distribution: The economic analysis must take into account the infrastructure and distribution expenses related to biodiesel, including facilities for storage, transportation, and blending. The economic viability of using biodiesel can be aided by investments in efficient distribution networks and infrastructure development.

It is significant to note that the availability of feedstock, the volume of production, governmental regulations, market demand, and infrastructure advancement all have an impact on how economically viable biodiesel production is in India. In India, ongoing efforts are needed to improve manufacturing procedures, cut prices, and foster a favourable business climate for biodiesel.

Conclusion

The manufacturing of biodiesel presents an opportunity to solve the issues of reliance on fossil fuels and environmental concerns. Sustainable energy sources can be promoted and greenhouse gas emissions can be decreased by using renewable feedstocks to make biodiesel. With the assistance of government programmes and policies, India in particular has made notable advancements in the production of biodiesel.

For the biodiesel business to grow sustainably, there are still obstacles to be solved. It is nevertheless a concern that significant supplies of acceptable feedstocks, especially inedible oilseeds, are not readily available. Enhancing feedstock productivity and looking into new feedstock possibilities are the main goals of research. In order to preserve the biodiesel's compatibility with diesel engines and infrastructure, it is also critical to maintain its quality and standards.

Future growth in feedstock cultivation, oil extraction methods, and production procedures will determine the viability of biodiesel production. To improve the productivity and economics of biodiesel production, lower production costs, and maximise the overall sustainability of the biodiesel business, research and development initiatives are required.

Additionally, ongoing efforts are needed to raise awareness, stimulate regulatory support, and promote investment in the biodiesel industry. Collaboration between governments, academic institutions, and industry players will be essential to the growth of biodiesel production and use, which will pave the way for a greener and more sustainable energy future.

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