IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

Sustainable Biodiesel Production in India: Renewable Feedstocks, Catalytic Processes, Fuel Quality, Challenges and Future Perspectives

Akshay B. Randive[1], Uttam B. Chougale[2], Revannath V. Ligade[3], Parmeshwar T. Lokhande[4], Sneha K. Gaikwad[5]
[1,5]Department of Humanities and General Science
SVERI's College of Engineering (Poly.), Pandharpur, Maharashtra, India.
[2]Department of Chemistry
Karmaveer Hire Arts, Commerce, Science and Education College, Gargoti, Maharashtra, India.
[3]Dr. Ganpatrao Deshmukh Mahavidyalaya, Sangola, Maharashtra, India.
[4]Department of Chemistry, Walchand College of Arts and Science, Solapur, Maharashtra, India.
[5]Swami Vivekanand Institute of Technology (Poly.), Solapur, Maharashtra, India

Abstract: *The production of biodiesel from renewable and non-edible feedstocks presents a strategic pathway to strengthen energy security, reduce greenhouse gas emissions, and mitigate the food-versus-fuel conflict. Biodiesel chemically consists of fatty acid methyl esters (FAME) synthesized via the esterification of free fatty acids and the transesterification of triglycerides with short-chain alcohols (such as methanol) in the presence of acid, base, or heterogeneous catalysts. In India, the technological and feedstock landscape focuses heavily on non-edible tree-borne oilseeds (such as Jatropha curcas and Pongamia pinnata) and waste streams like used cooking oil (UCO). While regulatory frameworks like the National Policy on Biofuels and Bureau of Indian Standards (BIS) specifications provide structured support, commercial scale-up continues to face hurdles including decentralized feedstock supply chains, raw material cost volatility, and strict quality compliance. Addressing these challenges through waste aggregation models, advanced heterogeneous catalysis, and integrated biorefineries can significantly enhance the commercial viability and long-term prospects of India's low-carbon transport transition.*

Keywords: Biodiesel, Renewable, Feedstock, Catalysis

I. INTRODUCTION

Traditional petroleum fuels contribute significantly to water pollution across every stage of their lifecycle. Industrial effluents from oil refining, accidental fuel leaks, and the deposition of atmospheric emissions into rivers and oceans [1] introduce dangerous pollutants into critical freshwater systems.[2] These contaminants disrupt aquatic food webs, degrade drinking water quality,[3] and create long-term ecological damage in downstream aquatic environments. [4]

Evolution and Historical Trajectory of Biodiesel: From Early Roots to the Indian Context

The Pre-Industrial and Experimental Era (Mid-19th to Early 20th Century). The scientific foundation of biodiesel predates the invention of the conventional petroleum-powered compression-ignition engine. The chemical process central to biodiesel production—transesterification-was first documented in 1853 by scientists E. Duffy and J. Patrick, who successfully broke down vegetable oil molecules using alcohol and alkali.[5] Decades later, in 1893, German inventor Rudolf Diesel engineered his revolutionary compression-ignition engine, which he famously demonstrated at the 1900 Paris Exposition running entirely on peanut oil. Diesel strongly advocated for plant-based oils, predicting in a 1912 address that biomass fuels would eventually become just as vital as petroleum and coal products. After the massive commercial discovery of cheap, abundant crude oil reservoirs worldwide, the automotive industry rapidly re-engineered engines to run on refined petroleum diesel, sidelining vegetable oils for several decades.

The Foundation of Modern Chemistry and Wartime Revivals (1930s–1940s)

The transition from raw plant oils-which suffered from extreme viscosity and caused heavy carbon deposits in engines-to modern-style refined esters took place in the 1930s. In 1937, Belgian scientist Georges Chavanne of the University of Brussels secured a patent for transforming vegetable oils via alcohol-based transesterification (fatty acid esters) specifically to be used as a stable substitute for diesel fuel. During World War II, severe petroleum scarcity forced several resource-strapped nations to temporarily revive the direct use of vegetable and animal oils to sustain agricultural and transport machinery.[6]

The Energy Crisis and Industrialization (1970s–1990s)

The global petroleum crises of the 1970s shattered faith in uninterrupted fossil fuel supply chains, triggering renewed global scientific interest in renewable transport fuels. In 1977, Brazilian scientist Expedito Parente invented and filed the patent for the first industrial-scale process to manufacture standardized biodiesel. By the early 1980s, researchers in South Africa successfully refined sunflower-derived methyl esters to match commercial engine standards. This momentum shifted to Europe, where the world’s first pilot plant opened in Austria in 1987, followed quickly by the first full-scale commercial rapeseed-based biodiesel plant in 1989. The term "biodiesel" itself gained mainstream acceptance during this era, first appearing in trade literature out of Australia in 1984.[7]

Evolution of the Biodiesel Sector in India

India’s engagement with alternative fuels has evolved through distinct phases driven primarily by energy security imperatives and heavy crude import dependency: Early Exploration of Tree-Borne Oilseeds (Early 2000s): Recognizing that importing crude oil strains the national economy, the Government of India shifted its focus toward utilizing degraded, uncultivated lands. In 2003, the Planning Commission released a comprehensive report on development of biofuels, which led to the formulation of the National Biofuel-Policy initiative.[8]

The Jatropha Phase: The early policy era heavily championed Jatropha curcas as a miraculous non-edible drought-resistant oilseed capable of growing on wastelands without threatening food crops. However, due to agronomic hurdles, lower-than-anticipated seed yields under un-irrigated conditions, and unorganized supply chains, initial large-scale plantation models faced commercial stagnation. Modern Strategic Pivot (Post-2018): Learning from early setbacks, India revised its roadmap via the National Policy on Biofuels (2018) and subsequent amendments. The strategy shifted toward a decentralized feedstock model prioritizing Used Cooking Oil (UCO) aggregation via urban commercial food networks alongside regionally resilient non-edible trees like Pongamia pinnata (Karanja) and Madhuca indica (Mahua). Today, integration with public oil marketing companies (OMCs) and adherence to strict Bureau of Indian Standards (BIS IS 15607) specifications anchors biodiesel as a vital pillar in India's transition toward low-carbon domestic energy independence.[9,10]

II. BIODIESEL PRODUCTION: PROCESS ENGINEERING AND STANDARDIZATION

Biodiesel principally comprising fatty acid methyl esters (FAME) or fatty acid ethyl esters (FAEE) is synthesized by converting raw triglycerides found in renewable, non-edible oils and fats through chemical esterification and transesterification pathways. Because non-edible feedstocks commonly carry high levels of moisture and free fatty acids (FFAs), industrial production follows a rigorous, multi-stage processing train to transform crude biomass into high-grade engine-ready fuel shown in fig.1

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

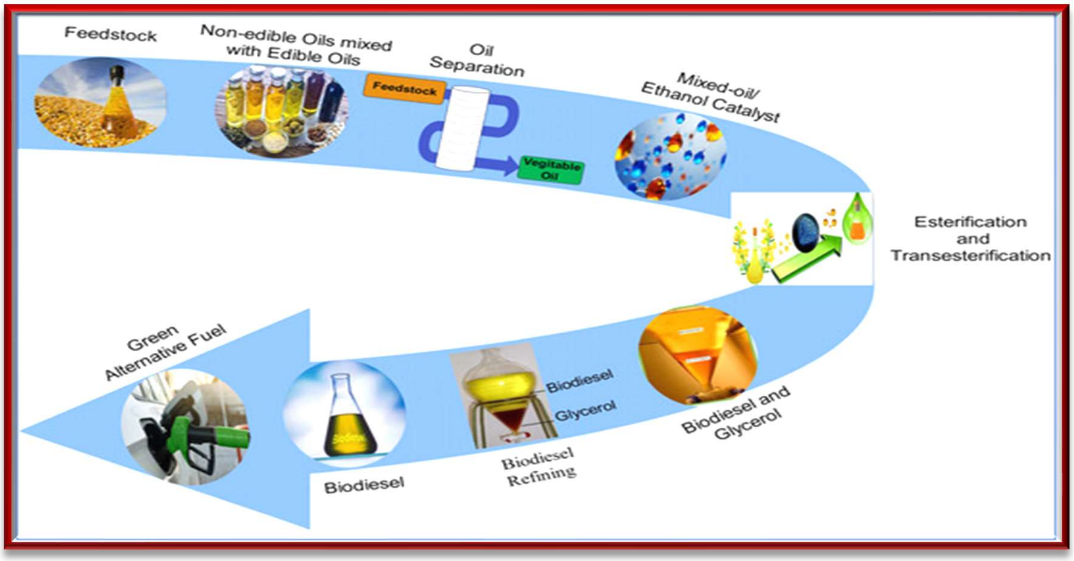

Figure 1. **Schematic diagram of biodiesel production line Adapted from Sustainability Volume 15 Issue 24 10.3390/su152416550 MDPI** [6]

2.1 Industrial Production Workflow:

The end-to-end manufacturing process from raw biological material to finished storage involves seven primary operational steps:

Storage and Feedstock Preparation: Raw non-edible oils or waste streams are received and stored in industrial holding tanks. Initial mechanical or coarse filtration is performed at this stage to remove suspended solid debris, impurities, and particulate matter before the oil is transferred to the reaction section.[11]

a) Acid Esterification: When the feedstock contains high concentrations of free fatty acids (>1%), direct base-catalyzed transesterification fails due to soap formation (saponification). To prevent this, the filtered oil is routed to an esterification reactor. An acid catalyst (typically sulfuric acid) is dissolved in short-chain alcohol, usually methanol, and mixed with the pre-heated oil. This step converts the FFAs into methyl esters, after which the mixture is dewatered to prepare it for the main conversion stage.[12]

b) Base Transesterification: The pretreated triglycerides are reacted with an excess of alcohol in the presence of an alkaline catalyst (such as sodium hydroxide or potassium hydroxide). This catalytic conversion cuts the molecular weight of the oil down to approximately one-third, drastically reduces kinematic viscosity (approximating petro-diesel specs), improves volatility, and substantially lowers the pour point. The primary reaction yields raw biodiesel alongside a heavy glycerol by-product phase [13] shown in fig.2

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

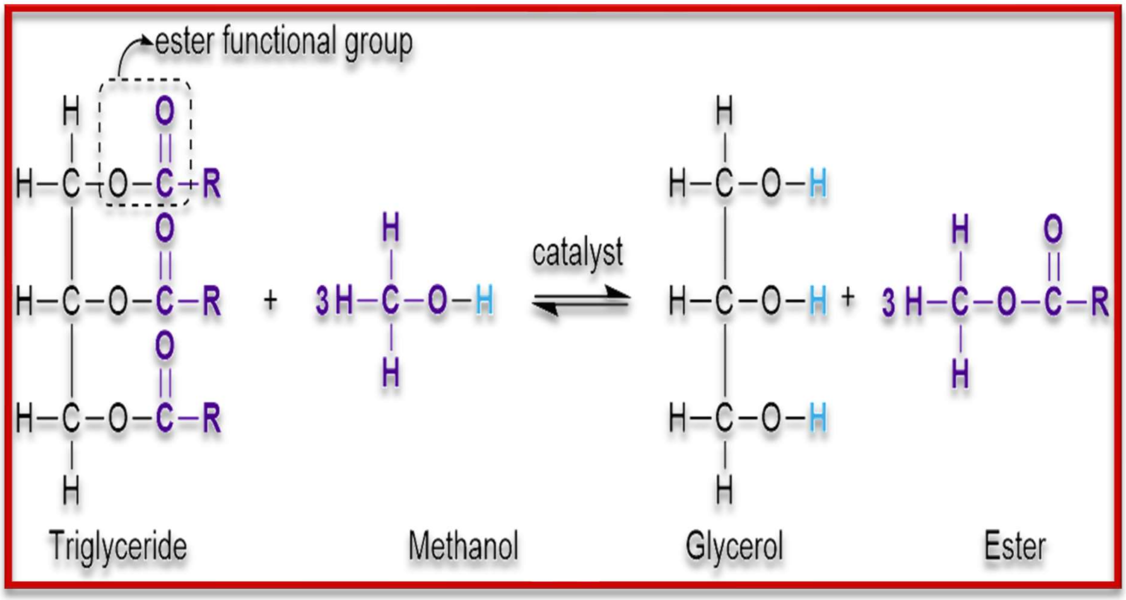

Fig.2 Transesterification reaction for biodiesel synthesis

c) Decantation and Phase Separation: Because glycerol has low solubility in methyl esters, the mixture is settled in decantation tanks or fed into industrial centrifuges. Gravity-based settling is economical though time-consuming, cleanly separating the denser glycerol layer at the bottom from the upper biodiesel ester layer.[14]

d) Purification and Washing: The separated biodiesel layer contains trace residues of unreacted alcohol, residual catalysts, soaps, and ionic salts. Purification is achieved through water-washing (wet washing) or modern dry-washing techniques (utilizing synthetic silicates or ion-exchange resins) to clear out impurities and ensure low ash and mineral contents.

e) Storage and Preservation: Purified neat biodiesel (B100) requires careful storage management. To prevent catalytic degradation or rapid oxidation, storage tanks must avoid reactive metals such as copper, bronze, brass, lead, tin, and zinc. Preferred container materials include stainless steel, aluminum, fluorinated polymers, or specialized fiberglass. Because heat, light, and ambient oxygen accelerate fuel degradation, long-term storage exceeding four to five months requires specialized antioxidant stability additives.[15]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

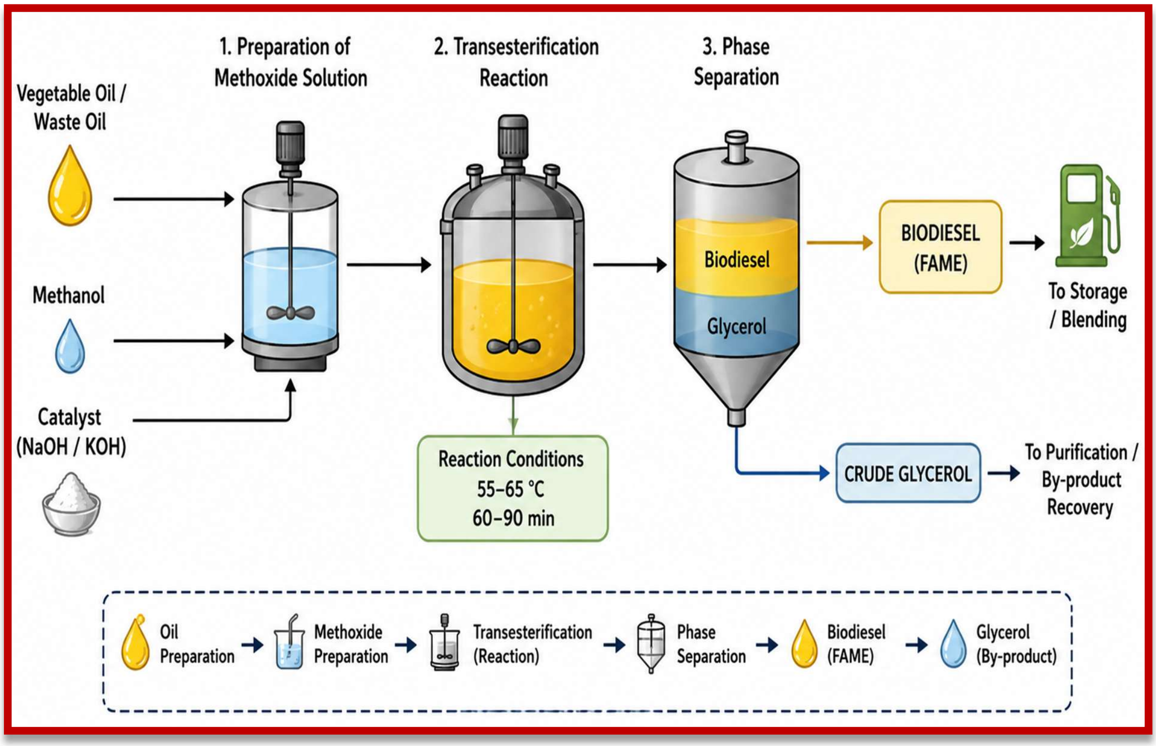

Fig.3: Simplified process flow diagram for conventional homogeneous catalytic biodiesel process.

f) Shipping and Transport: Transport tankers must be thoroughly cleaned and moisture-free prior to loading. Pure biodiesel carries a high flash point (exceeding 200 ^{0}F or roughly 93 ^{0}C), classifying it as a non-flammable liquid for safe transit without hazardous warning placards. However, cold weather insulation or heating mechanisms may be necessary to prevent clouding or gelling during winter transport. [16]

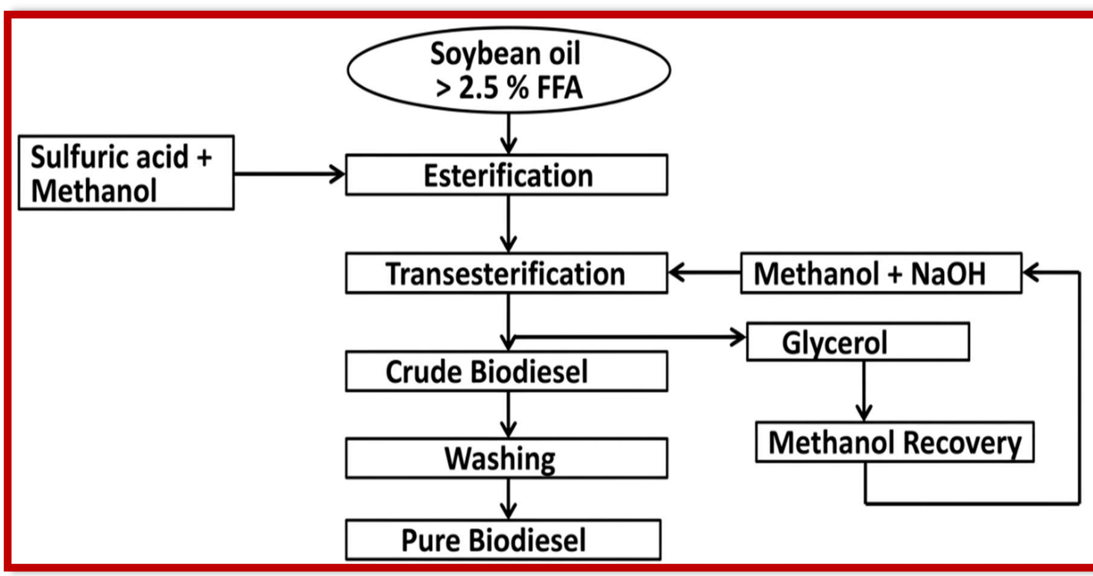

Fig. 4 Detailed Flowchart of Production Process of Bio-Diesel

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 1, August 2026 Impact Factor: 8.2

2.2 Fuel Blending Nomenclature and Standards:

Once processed, biodiesel is produced and distributed in a pure state known as B100 (neat biodiesel). For standard automotive retail and commercial applications, it is blended with petroleum diesel. These blends are categorized as BXX, where the numerical suffix indicates the volume percentage of pure biodiesel in the mixture (e.g., B5 or B20). To guarantee engine durability, fuel system compatibility, and emission compliance, regulatory bodies worldwide oversee strict quality parameters.[17]

International Benchmarks: ASTM International governs specifications through ASTM D6751 (for B100 blend stock in North America), while Europe relies on the EN 14214 technical standard.

The Indian Standards Framework: The Bureau of Indian Standards (BIS) established IS 15607 to regulate pure biodiesel (B100) intended for blending. Under Indian guidelines, conventional low-level blends such as B5 align seamlessly with standard automotive diesel specifications under IS 1460, while higher blend thresholds and specialized standalone applications continue to be expanded and updated by regulatory committees to support national energy targets.[18]

Specification of biodiesel (B100) as blending stock.	
Characteristics IS 1567 2005:	
Density, Kg / m3 860 –799	
Ester Content, % min. 96.4	
Flash point (closed cup), °C 121	
Water and sediment, mg / Kg, max. 500	
Kinematic viscosity at 40°C, mm2/s 2.4-6.0	
Oxidation Stability at 110°C, hours min. 6.5	
Rams bottom carbon residue, % mass, max.	**0.04**
Sulfated ash% mass, max.	**0.03**
Sulfur, mg / Kg max	**55**
Copper strip corrosion 3 hrs. 50°C	**Class 1**
Cetane Number, min.	**50**
Acid number, mg KOH/g, max.	**0.55**
Methanol or Ethanol, % m/m, max	**0.25**
Free glycerin, % mass	**0.025**
Total glycerine (free glycerine and unconverted glycerides combined), % by mass, max.	**0.30**
Group I Metal (Na+K), mg/Kg, max	**5**
Group II Metal (Ca+Mg), mg/Kg, max	**5**
Phosphorus content, mg/Kg, max	**10**

Table 1 Characteristics Specification of Biodiesel [19]

DOI: 10.48175/IJARSCT-38054

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

III. RAW MATERIALS REQUIRED FOR BIODIESEL PRODUCTION

The overall economic viability, environmental footprint, and commercial scalability of biodiesel production depend heavily on the choice of raw materials. To avoid competing with the human food chain and to minimize operating expenses, industrial production in India prioritizes non-edible organic feedstocks, supported by appropriate short-chain alcohols and catalytic agents.

3.1. Primary Feedstocks: Non-Edible Vegetable Oils and Waste Fats Because raw material procurement accounts for the vast majority of total biodiesel production costs, utilizing low-cost, non-food resources is essential for commercial competitiveness. Non-Edible Tree-Borne Oilseeds (TBOs): India possesses extensive wastelands well-suited for cultivating hardy, drought-tolerant, non-edible oil-bearing trees. Key domestic feedstocks include:

Jatropha curcas: Historically promoted for its rapid growth and high oil content.

Pongamia pinnata (Karanja): A native, robust tree widely distributed across riverbanks and forest fringes.[20] Madhuca indica (Mahua) and Azadirachta indica (Neem): Regional oilseeds utilized extensively by decentralized rural processing units.

Waste Lipids and Animal Fats: Used Cooking Oil (UCO): Representing a prime urban-proximate waste-to-wealth resource, UCO collection prevents environmental dumping and lowers feedstock acquisition costs.

Animal Tallow and Acid Greases: Byproducts from slaughterhouses and meat-processing industries (derived from cattle, poultry, and pork) serve as viable alternative lipids.[21] Because these fats are semisolid or solid at room temperature and often carry high free fatty acid (FFA) levels, they require specialized thermal pre-treatment and acid esterification before transesterification.[12]

Feedstock	Major advantage	Major limitation	Typical pre-treatment	Biodiesel potential
Soybean oil	Good availability	Food competition	Usually, minimal	High
Jatropha oil	Non-edible	High FFA in crude oil	Esterification	High
Karanja oil	Non-edible, locally relevant	High FFA	Esterification	High
Waste cooking oil	Low-cost waste resource	Variable FFA/moisture	Filtration + esterification	Very high
Animal fat	Low-cost feedstock	High melting point	Pre-treatment	High
Algal oil	Does not directly compete with food crops	Cultivation/harvesting cost	Lipid extraction	Emerging

Table 2. Comparison of biodiesel feedstock properties and processing requirements.

3.2. Alcohols Short-chain, low-molecular-weight alcohols are required to break down triglycerides via alcoholysis: Methanol (CH_3OH) The most widely utilized alcohol globally and in India due to its low cost and high reactivity in forming fatty acid methyl esters (FAME). Ethanol (CH_3CH_2OH) An alternative bio-alcohol that yields fatty acid ethyl esters (FAEE). While bio-ethanol enhances the green credentials of the fuel, it is more expensive and requires more rigorous water-removal processing compared to methanol.[22]

3.3. Catalysts and Auxiliary Materials Chemical catalysts are critical to accelerate reaction rates and maximize ester conversion yields:

Alkali (Base) Catalysts: Strong alkaline substances such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium methoxide (CH_3ONa), and potassium methoxide (CH_3OK) are deployed for low-FFA refined or pretreated oils.

Acid Catalysts: Sulfuric acid (H_2SO) or solid acid resins are utilized specifically during the preliminary esterification phase to convert high free fatty acids into esters without causing unwanted soap formation.[23]

Process and Packaging Materials: Auxiliary inputs include deionized water (for wet washing purification), synthetic silicates or ion-exchange resins (for dry washing), chemical stability additives to prevent oxidation during storage, and corrosion-resistant packaging containers (such as stainless steel, aluminum, or fluorinated high-density polyethylene drums) to ensure safe handling and extended shelf-life.

Catalyst	Advantages	Limitations	Reusability	Typical application
NaOH	Low cost, fast	Soap formation with high FFA	Poor	Low-FFA oils
KOH	Fast reaction	Soap formation	Poor	Low-FFA oils
H_2SO_4	Suitable for high FFA	Slow, corrosive	Poor	Esterification
CaO	Heterogeneous, reusable	Sensitive to moisture/CO_2	Better	Transesterification
Lipase	Mild conditions	Expensive	Potentially high	Advanced biodiesel

IV. STORAGE, HANDLING, AND QUALITY CONTROL OF BIODIESEL

Maintaining fuel integrity from the production facility to the vehicle fuel tank requires strict storage protocols and handling procedures. Because neat biodiesel (B100) and its higher-level blends possess unique chemical characteristics—such as high solvent potency, elevated oxidation susceptibility, and material incompatibility—proper infrastructure management is critical to prevent operational disruptions.[24]

4.1. Oxidation Stability and Deposit Solvency:

Oxidation Deterioration: Untreated biodiesel inherently exhibits lower oxidation stability than petroleum diesel. Exposure to atmospheric oxygen, ambient heat, and direct sunlight accelerates degradation, causing gum formation, increased viscosity, and higher acid numbers. To counteract this, synthetic or natural antioxidant additives are introduced during final processing if extended storage is anticipated.

Solvent Action and System Cleaning: Biodiesel acts as a strong organic solvent. When introduced into a fuel system previously operated on conventional petroleum diesel, it gradually dissolves legacy varnish and sludge deposits accumulated over years of use. These dislodged impurities travel downstream and clog fuel filters, necessitating more frequent filter replacements during the initial transition period until the system is completely cleaned.[25]

4.2. Microbial Contamination and Water Management

Biodegradability vs. Tank Contamination: While rapid biodegradability is an environmental advantage during accidental fuel spills, it makes stored biodiesel highly vulnerable to microbial proliferation (bacteria and fungi).

Housekeeping Protocols: Microbes thrive in the moisture interface layer (water bottoms) at the bottom of storage tanks. Microbial growth produces acidic byproducts that corrode infrastructure and clog vehicle fuel filters. Effective "good housekeeping" requires routine water draining, regular tank bottom sampling, and biocide treatments where necessary to maintain pristine fuel quality.[26]

4.3. Material Compatibility

Neat biodiesel (B100) reacts aggressively with specific metallic and polymeric materials:

Reactive Metals: Prolonged contact with copper, brass, bronze, lead, tin, or zinc (galvanized surfaces) catalyzes chemical degradation, producing metallic soaps and high sediment levels that foul fuel filters. Tanks and piping components must avoid these materials.

Plastics and Polymers: Standard high-density polyethylene or polypropylene can experience chemical permeation and softening over time when exposed to neat biodiesel. Approved storage materials include stainless steel, aluminum, fluorinated plastics, and specialized fiberglass.[27]

4.4. Quality Specifications and Visual Inspection Standards

To ensure uniform commercial performance, international guidelines (such as ASTM D6751) and domestic frameworks enforce strict physical cleanliness requirements:

Clarity and Freedom from Contaminants: Biodiesel fuel must remain visually clear and completely free of undissolved water, suspended matter, and heavy sediments.

Color Independence: Natural variations in feedstock origin can impart different hues (ranging from light yellow to amber) to the finished fuel; however, color does not serve as an indicator of overall fuel quality or specification compliance.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

Blending Limits: Modern technical specifications officially authorize standardized co-blending thresholds allowing up to 5% biodiesel inclusion in general commercial diesel pools without requiring engine re-engineering.[28]

V. HEALTH & SAFETY ASPECTS

Because biodiesel and its blend stocks are biodegradable, they may be useful in applications where biodegradability is desired (such as marine or agricultural applications). According to EPA Tier 2 requirements for fuel and fuel additive registration, emissions from engines using biodiesel blends have successfully undergone health effects testing. Diesel and biodiesel blends have been shown to lower CO, HC, and particle emissions. Because biodiesel has a greater flash point than petroleum-based diesel fuel, it can be transported and stored without the limitations that come with combustible materials. Biodiesel is typically considered harmless because it doesn't contain any toxic ingredients. Biodiesel biodegrades far more quickly than regular diesel, according to several studies. Users have benefited from this feature by switching from harmful petroleum fuel to biodiesel in environmentally sensitive places like wetlands, marine ecosystems, and national parks. Compared to kerosene (flash point: 38 to 72 ºC) and diesel (flash point: 52 to 96 ºC), biodiesel is significantly less hazardous because its flash point is higher than 100 degrees Celsius. Blends of biodiesel, however, will have flash points that are in between those of the two liquids.[29]

In India, the strategic push for biodiesel production serves as a critical mechanism to curb heavy crude oil import dependencies, mitigate carbon footprints, and stimulate local rural and urban-proximate green economies (such as regional biomass processing units across Maharashtra, Karnataka, and Uttar Pradesh) under the National Policy on Biofuels. Grounded by Bureau of Indian Standards (BIS IS 15607) quality compliance, the country's ecosystem heavily prioritizes non-edible resources—such as resilient tree-borne oilseeds (Jatropha and Karanja) and waste-to-wealth streams like Used Cooking Oil (UCO) aggregated via initiatives like RUCO. While state-run Oil Marketing Companies (OMCs like IOCL, BPCL, and HPCL) drive structured demand through regular Expression of Interest (EOI) procurement tenders and fixed pricing models, scaling the sector toward its long-term blending objectives continues to rely on overcoming decentralized supply chain fragmentation and formalizing efficient feedstock collection networks.[30]

VI. LAUNCH OF BIODIESEL (B5)

In the Northern Region, High-Speed Diesel (HSD) blended with 5% biodiesel (B5) was launched on August 10, 2015, to mark World Biofuel Day. The initial rollout commenced at a select Company Owned Company Operated (COCO) Retail Outlet fed from the Bijwasan installation. Following the initial launch, expansion was scheduled across key locations, including Bathinda, Salawas, Rewari, Jobner, Mathura, and Kanpur.[19]

VII. BIODIESEL APPLICATIONS

1. Transportation

Biodiesel's primary use is as a substitute or additive for petroleum diesel in road transportation. It is commonly blended into standard diesel at low concentrations (such as B5 or B20) and used in trucks, buses, passenger cars, and logistics fleets without requiring major engine modifications.

2. Off-Road Heavy Machinery

It acts as an effective fuel source for heavy-duty industrial and agricultural equipment, including tractors, construction vehicles, mining equipment, and forestry machinery.

3. Rail and Marine Transport

Rail networks and commercial shipping vessels utilize biodiesel blends to lower greenhouse gas emissions and comply with strict environmental regulations for freight and passenger transport.

4. Power Generation

Biodiesel fuels stationary diesel generators to provide electricity for off-grid operations, emergency backup systems, and commercial buildings.[31]

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, August 2026
Impact Factor: 8.2

5. Heating Oil

In cold-climate regions, biodiesel is mixed with conventional heating oil (often called Bioheat) to fuel residential and commercial furnaces, reducing domestic reliance on fossil fuels.

6. Lubricant and Cleaning Agent

Because of its high lubricity, biodiesel is frequently used as an additive to improve engine component lifespan. It also serves as an industrial solvent for cleaning equipment, removing grease, and assisting in oil spill remediation due to its non-toxic, biodegradable nature.[32]

VIII. CONCLUSION

Biodiesel enhances national energy security, protects the environment, and stimulates economic growth. Today, it is increasingly recognized as a viable alternative fuel not only in the Americas, but across the world. A primary driver behind the transition to biodiesel is energy security. By substituting imported petroleum with locally sourced feedstocks, nations can significantly reduce their dependence on foreign oil while strengthening domestic energy supplies. Importantly, biodiesel delivers this energy security alongside a substantial reduction in greenhouse gas emissions. While life-cycle energy balances remain a subject of ongoing study, biodiesel consistently demonstrates a net positive energy gain. Properly managed, biodiesel feedstocks can secure energy supplies, diversify fuel sources, and drive sustainable economic development.

Data availability: Not Applicable.

Declarations

Conflict of interest: The authors declare that they have no conflict of interest.

Research involving human and animal participant: This article does not contain any studies with human participants or animals performed by any of the authors. In this experiment, we did not collect any samples of human and animals.

REFERENCES

[1] R.A. Tavella, F.M.R. da Silva Júnior, M.A. Santos, S.G.E.K. Miraglia, R.D. Pereira Filho, A Review of Air Pollution from Petroleum Refining and Petrochemical Industrial Complexes: Sources, Key Pollutants, Health Impacts, and Challenges, ChemEngineering 9 (2025). https://doi.org/10.3390/chemengineering9010013.

[2] P.T. Lokhande, D.K. Narale, S.M. Deshmukh, B.R. Torane, V.T. Vader, Exploring the photocatalytic degradation of Direct Black 122 dye using Ni-doped magnesium ferrichromite nanoparticles synthesized by sol–gel method, Ionics (Kiel). 31 (2025) 11947–11959. https://doi.org/10.1007/s11581-025-06673-8.

[3] M. Rose, Risks Associated with Dietary Exposure to Contaminants from Foods Obtained from Marine and Fresh Water, Including Aquaculture, Int. J. Environ. Res. Public Health 23 (2026). https://doi.org/10.3390/ijerph23010085.

[4] P.T. Lokhande, S.M. Deshmukh, D.K. Narale, H. Shaikh, S.M. Al-Zahrani, M.A. Alam, M.S. Tamboli, N.T.N. Truong, V.T. Vader, Sol–gel assisted incremental substitution of Ni with Ba in barium ferrichromites and their photocatalytic activity, J. Mater. Sci. Mater. Electron. 35 (2024) 769. https://doi.org/10.1007/s10854-024-12479-7.

[5] M. Okoronkwo, A. Galadima, L. Luter, Advances in Biodiesel synthesis: from past to present, Elixir Appl. Chem. 43 (2012) 6924–6945.

[6] F. Musharavati, K. Sajid, I. Anwer, A.-S. Nizami, M.H. Javed, A. Ahmad, M. Naqvi, Advancing Biodiesel Production System from Mixed Vegetable Oil Waste: A Life Cycle Assessment of Environmental and Economic Outcomes, Sustainability 15 (2023). https://doi.org/10.3390/su152416550.

[7] D. Huang, H. Zhou, L. Lin, Biodiesel: an Alternative to Conventional Fuel, Energy Procedia 16 (2012) 1874–1885. https://doi.org/https://doi.org/10.1016/j.egypro.2012.01.287.

[8] M. Vijay, Tree-Borne Oilseed Cultivation: Research Gaps and Future Perspective, 52 (2024) 100–108.

[9] D. Neupane, D. Bhattarai, Z. Ahmed, B. Das, S. Pandey, J.K.Q. Solomon, R. Qin, P. Adhikari, Growing Jatropha (Jatropha curcas L.) as a Potential Second-Generation Biodiesel Feedstock, Inventions 6 (2021). https://doi.org/10.3390/inventions6040060.

[10] K. Kashe, D. Kgathi, M. Murray-Hudson, K. Mfundisi, Assessment of benefits and risks of growing Jatropha (Jatropha curcas) as a biofuel crop in sub-Saharan Africa: a contribution to agronomic and socio-economic policies, J. For. Res. 29 (2017) 1–12. https://doi.org/10.1007/s11676-017-0460-1.

[11] S. Mondal, A.V.P. Gurumoorthy, I.G. Moorthy, Sustainable production of biodiesel from non-edible kernel-derived feedstocks: A comprehensive review of production processes, properties, and optimization, Results Chem. 20 (2026) 102967. https://doi.org/https://doi.org/10.1016/j.rechem.2025.102967.

[12] H.H. Naseef, R.H. Tulaimat, Transesterification and esterification for biodiesel production: A comprehensive review of catalysts and palm oil feedstocks, Energy Convers. Manag. X 26 (2025) 100931. https://doi.org/https://doi.org/10.1016/j.ecmx.2025.100931.

[13] V.S. Shanthini, D. Chitra, G. Moorthy, Biodiesel: A comprehensive review of properties, catalyst types, and feedstock sources, Results Chem. 18 (2025) 102678. https://doi.org/https://doi.org/10.1016/j.rechem.2025.102678.

[14] D. Dimitrijevic, M. Bösenhofer, M. Harasek, Liquid–Liquid Phase Separation of Two Non-Dissolving Liquids—A Mini Review, Processes 11 (2023) 1145. https://doi.org/10.3390/pr11041145.

[15] K. Suthar, A. Dwivedi, M. Joshipura, A review on separation and purification techniques for biodiesel production with special emphasis on Jatropha oil as a feedstock, Asia-Pacific J. Chem. Eng. 14 (2019). https://doi.org/10.1002/apj.2361.

[16] D. Bradley, F. Diesenreiter, M. Wild, E. Trømborg, World Biofuel Maritime Shipping Study, 2009.

[17] D.E. Resource, Biodiesel : A Renewable , Domestic Energy Resource, (2026) 30–33.

[18] M. Ramos, A.P. Soares Dias, J. Puna, J. Gomes, J. Bordado, Biodiesel Production Processes and Sustainable Raw Materials, Energies 12 (2019) 4408. https://doi.org/10.3390/en12234408.

[19] A.B. Randive, S.K. Gaikwad, S.B. Khadake, H.M. Mallad, Biodiesel : A Renewable Source of Fuel, (2024). https://doi.org/10.48175/IJARSCT-22836.

[20] A. Kumar, S. Sharma, Potential non-edible oil resources as biodiesel feedstock: An Indian perspective, Renew. Sustain. Energy Rev. 15 (2011) 1791–1800. https://doi.org/https://doi.org/10.1016/j.rser.2010.11.020.

[21] S. Puhan, V. N, B. Rambrahamam, N. Govindan, Mahua (Madhuca indica) seed oil: A source of renewable energy in India, J. Sci. Ind. Res. (India). 64 (2005).

[22] G. Christophe, V. Kumar, R. Nouaille, G. Gaudet, P. Fontanille, A. Pandey, C. Soccol, C. Larroche, Recent developments in microbial oils production: a possible alternative to vegetable oils for biodiesel without competition with human food?, Brazilian Arch. Biol. Technol. 55 (2012) 29–46. https://doi.org/10.1590/S1516-89132012000100004.

[23] B. Karmakar, G. Halder, Accelerated conversion of waste cooking oil into biodiesel by injecting 2-propanol and methanol under superheated conditions: A novel approach, Energy Convers. Manag. 247 (2021) 114733. https://doi.org/https://doi.org/10.1016/j.enconman.2021.114733.

[24] Z. Mufidah, A. Tiguna, A. Haryanto, Stability of Pure Biodiesel (B100), Biodiesel Mixture (B40), and Petroleum Diesel (B0) Due to Storage, J. Tek. Pertan. Lampung (Journal Agric. Eng. 13 (2024) 900. https://doi.org/10.23960/jtep-l.v13i3.900-913.

[25] W.N.A. Wan Osman, M.H. Rosli, W.N.A. Mazli, S. Samsuri, Comparative review of biodiesel production and purification, Carbon Capture Sci. Technol. 13 (2024) 100264. https://doi.org/https://doi.org/10.1016/j.ccst.2024.100264.

[26] F. Bücker, N. Santestevan, L. Roesch, R. Jacques, M. do C. Peralba, F. Camargo, F. Bento, Impact of biodiesel on biodeterioration of stored Brazilian diesel oil, Int. Biodeterior. Biodegrad. - INT BIODETERIOR Biodegrad 65 (2011) 172–178. https://doi.org/10.1016/j.ibiod.2010.09.008.

[27] M. Coronado Ortega, G. Montero, C. Garcia, M. Wiener, B. valdez salas, A. Eliezer, Equipment, Materials, and Corrosion in the Biodiesel Industry, Mater. Perform. 58 (2019). https://doi.org/10.5006/MP2019_58_2-34.

[28] S.F. Basumatary, S. Brahma, M. Hoque, B.K. Das, M. Selvaraj, S. Brahma, S. Basumatary, Advances in CaO-based catalysts for sustainable biodiesel synthesis, Green Energy Resour. 1 (2023) 100032. https://doi.org/https://doi.org/10.1016/j.gerr.2023.100032.

[29] S. Shanigarapu, An overview of Biodiesel, 2019.

[30] M.S. Khan, A. Ahmad, India's Biofuel Transition and Energy Independence: A Comparative Policy Analysis of Union Budget 2026–27, 13 (2026) a634–a639.

[31] D.L. Loo, Y.H. Teoh, H.G. How, J.S. Teh, L.C. Andrei, S. Starčević, F. Sher, Applications Characteristics of Different Biodiesel Blends in Modern Vehicles Engines: A Review, Sustainability 13 (2021). https://doi.org/10.3390/su13179677.

[32] A REVIEW PAPER ON BIODIESEL : A, 6 (2019) 154–160.