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Jatropha Oil as a Non-Edible Feedstock for Biodiesel: A Comprehensive Review

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Abstract: Biodiesel continues to attract attention as a renewable alternative to fossil diesel, helping reduce greenhouse-gas emissions and strengthen energy security. Among non-edible oilseeds, *Jatropha curcas* stands out because of its high seed-oil yield and capability to grow on degraded or marginal lands. This review summarizes recent progress in producing biodiesel from Jatropha oil, including oil extraction methods, transesterification processes (homogeneous, heterogeneous, enzymatic, and supercritical), and optimization strategies aimed at improving yield, cost, and scalability. A range of fuel characterization techniques used to assess biodiesel quality: key physicochemical properties (viscosity, density, cold-flow behavior), chemical purity (free fatty acids, moisture, glycerol), and performance metrics (cetane number, oxidative stability, emissions) have been examined. While Jatropha biodiesel shows considerable promise, several barriers remain notably feedstock supply stability, land-use and sustainability challenges, catalyst efficiency, and techno-economic feasibility. Addressing these issues through improved agronomy, advanced conversion technologies, and valorization of by-products will be essential to strengthen the role of Jatropha-based biodiesel in a sustainable energy portfolio.

Keywords: *Jatropha curcas*, Biodiesel, Transesterification, Fuel quality, Characterization, Renewable energy

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1. Introduction

The growing concerns over climate change, depletion of petroleum reserves, and rising fuel demand have intensified global efforts to transition toward renewable energy sources [1]. Diesel fuel plays a central

role in transportation and agricultural sectors, but its continued use contributes significantly to greenhouse gas emissions and air pollution. Biodiesel has emerged as a viable alternative because it is biodegradable, sulfur-free, and capable of reducing particulate matter, carbon monoxide, and overall lifecycle CO₂ emissions relative to fossil diesel [2,3]. Biodiesel is commonly produced from triglyceride-rich feedstocks, including vegetable oils, animal fats, and waste cooking oils. However, the commercialization of biodiesel has been slowed by feedstock constraints and the ethical concerns associated with edible oil sources competing with food production [4]. These challenges have prompted significant interest in non-edible oil-bearing plants as more sustainable biodiesel feedstocks.

Jatropha curcas is one of the most promising candidates in this category. It is a hardy perennial shrub capable of thriving on degraded land with minimal agricultural inputs, which helps avoid competition with food crops and supports production in rural or dry regions [5,6]. *Jatropha* seeds contain 30 to 40 percent oil, making the crop suitable for large-scale biodiesel production once supply chains are fully developed [7]. In addition, the toxic nature of *Jatropha* seeds prevents their use in the food sector, strengthening their suitability for biofuel applications [8].

Considerable progress has been made in optimizing *Jatropha* oil extraction and improving transesterification efficiency. Research continues to explore homogeneous and heterogeneous catalysis, enzymatic conversion routes, and supercritical processing for enhanced reaction kinetics and fuel quality [9-11]. Alongside processing developments, fuel characterization plays an essential role in ensuring that *Jatropha* biodiesel meets international standards such as ASTM D6751 and EN 14214 [12]. Evaluating key physicochemical and combustion properties provides insight into handling, engine performance, and emissions characteristics.

Despite its potential, *Jatropha* biodiesel faces several important challenges, including yield variability due to genotype and environment, slow early crop establishment, supply chain immaturity, and processing economics that remain less favorable than conventional diesel [13,14]. Addressing these limitations is crucial to determining whether *Jatropha* can become a dependable, scalable, and environmentally responsible biodiesel source.

This review aims to (a) compile and compare current methods for oil extraction and biodiesel production from *Jatropha*, (b) survey advanced techniques for fuel characterization, (c) analyze benefits and risks (environmental, technical, socio-economic), (d) highlight opportunities for development, and (e) discuss the roles of key stakeholders - policymakers, researchers, and industry - in enabling widespread adoption.

2. Composition and Production Process of Biodiesel from Jatropha Oil

2.1 Feedstock Composition

Jatropha curcas seeds generally contain 30-40 percent oil by weight, with the majority of the lipids stored as triglycerides composed of long-chain fatty acids [15]. This lipid profile plays a major role in determining the quality and behavior of the resulting biodiesel. Oleic acid (C18:1) and linoleic acid (C18:2) are the dominant fatty acids in Jatropha oil, while smaller fractions of saturated fatty acids such as palmitic (C16:0) and stearic acid (C18:0) are also present [16]. The balance between unsaturated and saturated components contributes to desirable fuel properties including good ignition quality, moderate viscosity, and relatively stable performance under varying operating conditions.

Oil quality and composition may vary depending on genotype, environmental conditions, maturity at harvest, and seed storage, especially with regard to free fatty acid (FFA) content and moisture. These parameters directly influence downstream conversion efficiency, catalyst selection, and overall biodiesel quality [17]. **Table 1** summarizes the typical fatty acid distribution [18] found in Jatropha seed oil, a profile that supports its suitability as a non-edible feedstock for biodiesel production.

| Fatty Acid | Structure | % Composition Range |
|---------------------|-------------------|---------------------|
| Myristic (C14:0) | $C_{14}H_{28}O_2$ | 0-0.1 |
| Palmitic (C16:0) | $C_{16}H_{32}O_2$ | 14.1-15.3 |
| Palmitoleic (C16:1) | $C_{16}H_{30}O_2$ | 0-1.3 |
| Stearic (C18:0) | $C_{18}H_{36}O_2$ | 3.7-9.8 |
| Oleic (C18:1) | $C_{18}H_{34}O_2$ | 34.3-45.8 |
| Linoleic (C18:2) | $C_{18}H_{32}O_2$ | 29.0-44.2 |
| Linolenic (C18:3) | $C_{18}H_{30}O_2$ | 0-0.3 |
| Arachidic (C20:0) | $C_{20}H_{40}O_2$ | 0-0.3 |
| Behenic (C22:0) | $C_{22}H_{44}O_2$ | 0-0.2 |

Table 1. Fatty acid composition (%) of *Jatropha curcas* seed oil. This information is taken from reference number [18]

This composition [18] classifies Jatropha as an oleic–linoleic type oil, which is generally preferred for biodiesel because it provides a favorable cetane number and improved combustion behavior, while

retaining acceptable oxidative stability relative to oils with higher polyunsaturated content.

2.2 Oil Extraction

Before conversion into biodiesel, oil must be extracted from Jatropha seeds. Commonly used approaches, along with their advantages and limitations, appear in **Table 2**.

| Method | Advantages | Limitations |
|--|---|---|
| Mechanical pressing | Solvent-free; scalable; suitable for rural setups | Lower oil recovery; residual oil remains in cake |
| Solvent extraction (e.g., hexane) | High yield; efficient for industrial processing | Solvent handling required; higher operating cost |
| Hybrid (press + solvent) | Combines benefits of both methods | Requires two-stage processing |
| Supercritical CO ₂ extraction | No solvent residues; environmentally cleaner | High capital cost; specialized equipment required |
| Enzyme-assisted extraction | Mild conditions; lower thermal degradation risk | Currently experimental; enzyme cost and stability |

Table 2. Comparison of Jatropha Oil Extraction Methods

Hybrid methods (mechanical pressing followed by solvent extraction) remain common in industrial setups because they balance yield and cost effectively [19]. Emerging techniques like supercritical CO₂ and enzyme-assisted extraction show promise for environmentally friendly and high-purity oil extraction, although scale-up remains limited [20, 21].

2.3 Transesterification Process

Conversion of triglyceride-rich Jatropha oil into fatty acid methyl esters (FAME), i.e., biodiesel, occurs through a transesterification reaction between triglycerides and a short-chain alcohol, typically methanol, producing FAME and glycerol as a by-product. The fundamental chemical mechanism of this conversion, involving stepwise transformation of triglycerides into diglycerides, monoglycerides, and finally glycerol, is illustrated in Figure 1. This reaction pathway supports all catalytic routes used in Jatropha biodiesel production, irrespective of catalyst type.

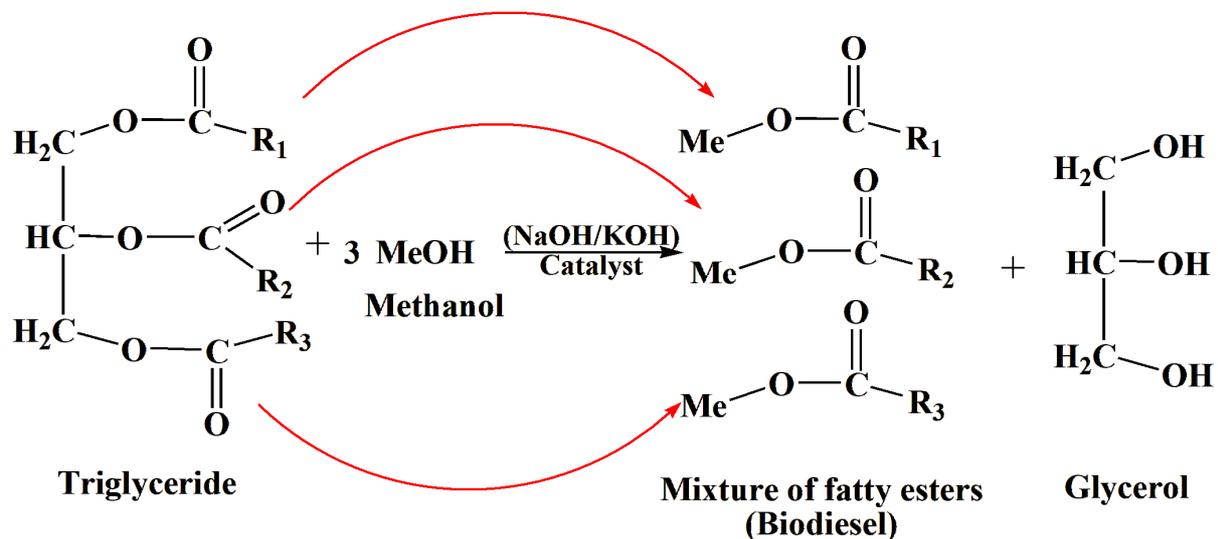


Figure 1. Chemical transesterification reaction mechanism converting triglycerides in Jatropha oil to fatty acid methyl esters (FAME) and glycerol.

Several transesterification approaches have been investigated for Jatropha oil, differing mainly in catalyst type, operating conditions, reaction kinetics, and suitability for oils with varying free fatty acid (FFA) content. A comparative overview of the major transesterification techniques is presented in Table 3.

| Method | Advantages | Limitations / Challenges |
|--------------------------------|---|--|
| Homogeneous (alkaline/acid) | High reaction rates; well-established processes | Sensitive to FFAs; soap formation; catalyst removal |
| Heterogeneous (solid) | Easier catalyst separation; catalyst reusability | Slower kinetics; mass-transfer limitations |
| Enzymatic (lipase) | Mild reaction conditions; high selectivity; less waste | High enzyme cost; sensitivity to water and inhibitory compounds; slower rates |
| Supercritical methanol | No catalyst required; rapid conversion; high-purity output | High pressure/temperature; energy-intensive |

Table 3. Comparison of Transesterification Techniques for Jatropha Biodiesel

For Jatropha oil containing elevated free fatty acid (FFA) levels, a preliminary acid-catalyzed esterification step is often required prior to alkaline transesterification to avoid soap formation and reduced biodiesel yield. During esterification, FFAs react with alcohol in the presence of an acid catalyst (such as sulfuric acid), converting FFAs into methyl esters and reducing the acid value of the oil to levels suitable for subsequent base-catalyzed transesterification. Once the FFA content is sufficiently lowered, efficient

conversion of triglycerides into biodiesel and glycerol can be achieved.

Homogeneous alkaline catalysis using catalysts such as NaOH or KOH remains the most widely applied commercial method because of its simplicity, low catalyst cost, and high reaction rates, provided the feedstock oil has low FFA and moisture content [22,23]. Under optimized conditions, conversion efficiencies exceeding 95% are commonly reported. However, homogeneous systems suffer from poor catalyst reusability, soap formation, and increased downstream purification costs due to extensive wastewater generation.

Heterogeneous catalysts, including metal oxides and solid base catalysts, offer advantages in terms of catalyst separation and reusability, reducing waste generation and simplifying product purification [22-24]. Quantitatively, heterogeneous systems typically achieve conversion efficiencies in the range of 85-95%, depending on catalyst composition and reaction conditions. Their broader industrial adoption is limited by slower reaction kinetics, diffusion resistance, and gradual catalyst deactivation during repeated cycles, which can offset operational advantages.

Enzymatic transesterification using lipases has attracted attention because it operates under mild reaction conditions, exhibits high selectivity, and tolerates high-FFA feedstocks without soap formation [22,25]. Enzymatic systems can achieve biodiesel yields above 90%, but their industrial feasibility remains constrained by high enzyme cost, limited operational lifetime, sensitivity to alcohol inhibition, and slower reaction rates compared with chemical catalysis.

Supercritical methanol processing eliminates the need for any catalyst and enables near-complete conversion within short reaction times, producing high-purity biodiesel [26]. Despite these advantages, the requirement for elevated temperatures and pressures results in high energy consumption and capital investment, restricting its application primarily to specialized or integrated biorefinery concepts rather than conventional biodiesel plants.

A critical comparison of these emerging routes highlights clear trade-offs between conversion efficiency, catalyst cost, energy demand, and scalability. While laboratory-scale studies often report high yields, many promising approaches have not progressed to commercial deployment due to challenges related to catalyst or enzyme durability, regeneration efficiency, energy-intensive operating conditions, and difficulties associated with scale-up and continuous operation. In addition, the lack of long-term pilot-scale data and comprehensive techno-economic assessments has hindered confident industrial adoption.

Optimization of key process parameters, including alcohol-to-oil molar ratio, catalyst concentration,

reaction temperature, residence time, and mixing intensity, remains essential for maximizing biodiesel yield while minimizing energy input and by-product formation [22-26]. The overall sequence of Jatropha biodiesel production, from oil extraction through transesterification and final purification, is summarized in Figure 2, highlighting the integration of reaction chemistry with downstream processing steps.

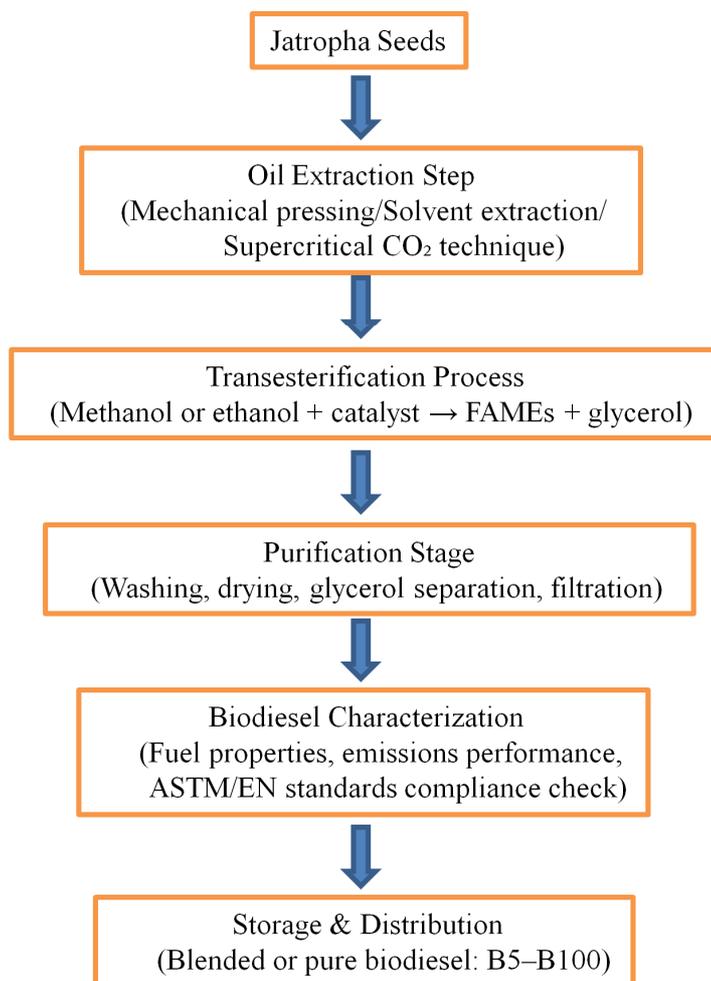


Figure 2. Schematic flow of Jatropha biodiesel production including oil extraction, transesterification, and purification.

2.4 Purification and Fuel Quality Assurance

After conversion, biodiesel must be separated from glycerol and purified to remove residual alcohol, catalyst, soap, and other impurities. Final purification via washing or dry purification methods is necessary to meet international fuel standards (such as ASTM D6751, EN 14214). Adequate purification ensures acceptable physical properties (viscosity, density), chemical purity, cetane number, and cold-flow performance for safe storage, handling, and engine compatibility [27]. Key fuel properties of Jatropha biodiesel compared with conventional diesel are summarized in **Table 4** to highlight performance

differences relevant to handling, storage, and engine operation. The data show [28] that Jatropha biodiesel has a higher flash point and negligible sulfur, improving storage safety and reducing SO_x emissions. Its higher viscosity and higher cold flow temperatures indicate potential challenges for fuel handling in colder climates, while the cetane number falls within acceptable ranges for diesel engines.

| Property | Jatropha Biodiesel | Diesel Fuel |
|--|----------------------|-------------|
| Specific gravity at 15°C | 0.86–0.93 | 0.82–0.86 |
| Calorific value (MJ kg ⁻¹) | 38-42 | ~42 |
| Pour point (°C) | -3 | -35 to 15 |
| Cloud point (°C) | 2 | -15 to 5 |
| Flash point (°C) | 210-240 | 50-98 |
| Cetane number | 38-51 (can reach 57) | 40-55 |
| Sulfur content (%) | ~0.13 | ~1.2 |
| Viscosity at 30°C (cSt) | 37-55 | 1.3-4.1 |

Table 4. Fuel characteristics of Jatropha biodiesel compared with petroleum diesel. This information is extracted from reference [28]

3. Key Benefits of Jatropha Biodiesel

3.1 Environmental Benefits

- **Reduced greenhouse-gas emissions:** Because the carbon in biodiesel originates from atmospheric CO₂ absorbed during plant growth, net CO₂ emissions are significantly lower than fossil diesel over the life cycle. Some life-cycle studies report a 50-70% reduction in greenhouse-gas emissions depending on cultivation and processing conditions [29].
- **Lower harmful emissions:** Compared with conventional diesel, biodiesel combustion typically yields lower particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons. Although nitrogen oxides (NO_x) sometimes increase slightly, such effects can often be mitigated through engine tuning or blending strategies [30].
- **Sulfur-free and biodegradable:** Jatropha biodiesel contains negligible sulfur, reducing sulfur dioxide emissions. Its biodegradability and lower toxicity mean spills pose less environmental risk compared with fossil diesel [31].

3.2 Technical Benefits

- **Improved lubricity:** Biodiesel molecules enhance fuel lubricity, reducing wear on fuel pumps and injectors, which can extend engine life and reduce maintenance [32].
- **Higher cetane number:** The typical fatty acid profile of Jatropha biodiesel supports a higher cetane number than many fossil diesels, promoting easier ignition, smoother combustion, and potentially improved fuel economy under suitable conditions [32].
- **Compatibility and flexibility:** Biodiesel can be used in existing diesel engines without major modifications, either as pure biodiesel (B100) or as blended fuel (e.g., B5-B20), facilitating gradual adoption [32].

3.3 Socio-Economic Benefits

- **Energy security and rural development:** Domestic production of biodiesel from Jatropha reduces dependence on imported fossil fuels. Cultivation on marginal lands supports rural economies, creates jobs, and can contribute to decentralized energy supply in remote regions [33, 34].
- **Use of marginal lands:** Since Jatropha can grow on degraded or barren lands, its cultivation minimizes competition with food crops mitigating food vs. fuel concerns [33, 34].
- **By-product valorization:** Seed cake, glycerol, and other by-products from biodiesel production can be used in biofertilizers, biogas production, or other applications, supporting a circular economy approach and improving overall process economics [34].

A simplified carbon-neutral energy cycle for Jatropha biodiesel is shown in Figure 3, emphasizing how plant growth offsets CO₂ emitted during fuel combustion.

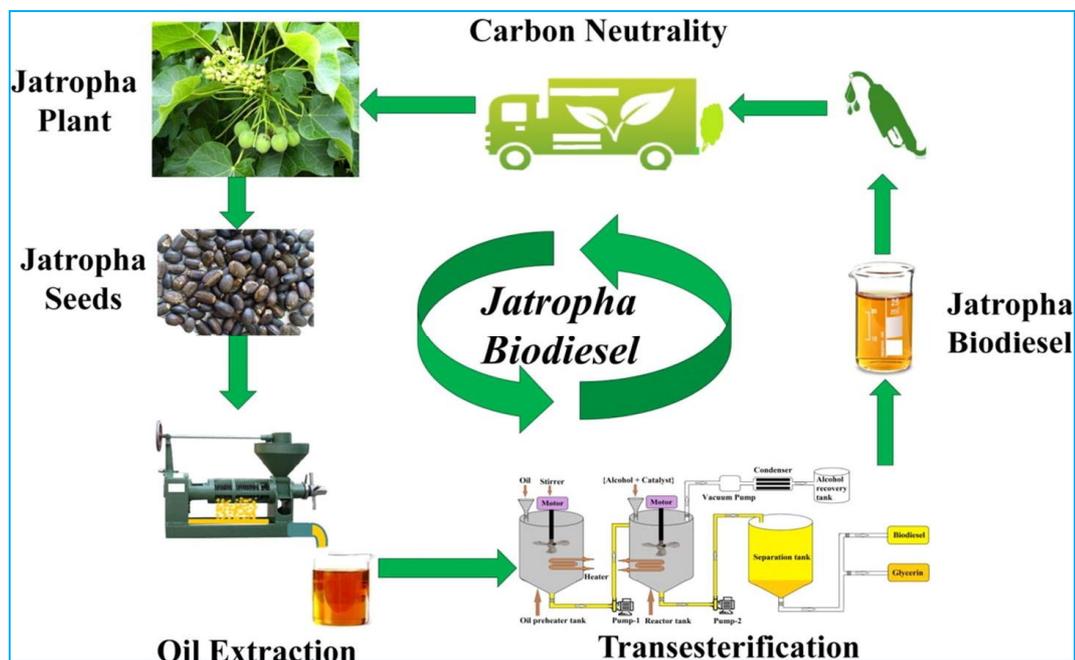


Figure 3. Carbon-neutral pathway associated with Jatropha biodiesel, linking plant growth, oil processing, fuel use, and atmospheric carbon cycling taken from reference [5]

4. Potential Environmental and Socio-Economic Challenges

Scaling up Jatropha biodiesel production especially to meet large-scale demand poses several environmental and social concerns (summarized in **Table 5**).

4.1 Land Use Change and Biodiversity

Expansion of Jatropha plantations may lead to conversion of natural ecosystems (forest, grasslands), causing biodiversity loss, soil degradation, and carbon release from vegetation and soils potentially offsetting the Greenhouse Gas (GHG) benefits of biodiesel [31, 33, 35]. Although the crop can grow on marginal lands, pressure to maximize yield might drive cultivation into ecologically sensitive or prime agricultural lands, especially where land governance is weak.

4.2 Water Use and Pollution

While Jatropha is often labeled drought-tolerant, achieving commercially viable yields on marginal soils sometimes requires significant irrigation, especially in dry regions. This can intensify water scarcity and impact downstream availability of water for local communities and agriculture. In addition, use of fertilizers and pesticides to boost productivity raises concerns about water pollution and ecosystem impacts [35, 36].

4.3 Soil Fertility and Agricultural Sustainability

Continuous monoculture of Jatropha may deplete soil nutrients, reduce organic matter, and degrade soil structure over time particularly in marginal or degraded soils. Heavy reliance on chemical fertilizers damages long-term sustainability [36, 37]. Without appropriate soil management strategies (e.g., crop rotation, agroforestry, organic amendments), the environmental benefits may shrink over successive cultivation cycles.

4.4 Lifecycle GHG Trade-offs

While tailpipe emissions improve with biodiesel use, indirect impacts such as land-use change emissions, energy-intensive processing (especially with supercritical methods), and fertilizer-related emissions can erode or even eliminate net GHG advantages [37].

4.5 Social and Economic Concerns

Large-scale cultivation may challenge land tenure systems, potentially displacing smallholders or indigenous communities, undermining food security, and leading to social inequities [33, 34]. Without transparent benefit-sharing and inclusive policies, the social advantages of Jatropha biodiesel may not materialize.

| Risk Category | Potential Negative Impact | Mitigation Strategy |
|-------------------------|---|---|
| Land use & biodiversity | Deforestation, habitat loss, carbon release | Use degraded/marginal lands; agroforestry; land-use zoning |
| Water resources | Water scarcity, pollution | Rain-fed cultivation; drip irrigation; minimal agrochemical use |
| Soil degradation | Nutrient depletion, erosion | Crop rotation; organic amendments; cover crops |
| GHG emissions | Emissions from land conversion, fertilizers, energy use | Life-cycle planning; carbon accounting; by-product valorization |
| Social / Economic | Displacement, inequity | Transparent land rights; community engagement; fair benefit-sharing |

Table 5. Risks of Large-Scale Jatropha Cultivation and Mitigation Strategies

5. Opportunities for Further Development

5.1 Feedstock Improvement & Diversification

- **Genetic and agronomic research:** Breeding or selecting *Jatropha* varieties with higher oil yield, lower phorbol ester content (reducing toxicity), and improved drought/pest resistance would significantly enhance feedstock reliability and safety. Precision agronomy, soil testing, optimized fertilization; pest management can further boost yields without excessive inputs [38].
- **Diversified feedstock strategies:** Relying solely on *Jatropha* may present risks. Exploring additional non-edible oilseed crops (e.g., *Pongamia*, *Camelina*) or non-seed feedstocks (e.g., algae, waste oils) can spread risk and reduce land-use pressure [38].

5.2 Advances in Conversion Technologies

- **Improved catalysis and process design:** Further development of robust, low-cost heterogeneous catalysts, immobilized enzymes, and continuous-flow supercritical systems could improve conversion efficiency, lower energy use, and reduce waste making production more economically viable at scale [22-25].
- **Biorefinery integration:** Valorization of by-products (seed cake for biofertilizer or biogas; glycerol for chemical feedstocks) can improve overall economics, reduce waste, and support circular bioeconomy models [39].

5.3 Renewable Energy Integration & Decentralized Production

Using renewable-powered extraction (e.g., solar energy for seed drying or oil extraction), or employing residue-based combined heat and power (CHP) systems, can reduce reliance on fossil energy during processing, boosting overall sustainability [40]. Decentralized biodiesel production in rural communities can enhance energy access and stimulate local economies.

5.4 Policy, Standards, and Market Support

- Government support via **subsidies, tax incentives, or low-interest loans** for biodiesel production and blending can improve economic competitiveness [41].
- Implementation of **renewable fuel mandates** (e.g., B5-B20 biodiesel blending) provides stable demand and encourages investment [42].

- Support for continued **R&D**, particularly in feedstock improvement, catalysis, life-cycle assessment (LCA), and socio-economic impact studies, is essential to build a robust knowledge base and promote sustainable practices [42].

5.5 Sustainability Assessment and Certification

Comprehensive LCAs should guide decisions on cultivation area, feedstock sourcing, and processing methods to maximize net GHG reduction while minimizing impacts on water, land, and biodiversity [43]. Development of certification schemes for sustainably produced biodiesel would help build trust, ensure quality, and facilitate market acceptance.

6. Roles of Stakeholders: Policymakers, Researchers, and Industry

The full realization of Jatropha biodiesel's potential depends on coordinated actions by three major stakeholder groups:

- **Policymakers:** Implement enabling frameworks, blending mandates, incentives, land-use regulations to stimulate adoption and guide sustainable land allocation.
- **Researchers:** Focus on agronomy, breeding, catalysis innovation, process optimization, LCA, and socio-economic assessments to resolve technical and environmental bottlenecks.
- **Industry:** Translate scientific advances into practical, scalable production, distribution, and commercialization; invest in pilot plants, build supply chains, ensure quality control, and engage consumers.

Public-private partnerships, demonstration projects, and pilot-scale biorefineries will be essential to bridge the gap between research and commercial deployment.

7. Conclusion

Biodiesel derived from *Jatropha curcas* offers a compelling sustainable alternative to fossil diesel. Its cultivation on marginal lands, combined with advances in extraction and conversion technologies, positions it as a promising contributor toward renewable energy goals, emissions reduction, and rural economic development. Nonetheless, key challenges must be addressed: stable and sustainable feedstock supply, catalyst efficiency, process economics, environmental risks, and social impacts. Realizing the full potential of Jatropha biodiesel depends on concerted efforts in research, technology development, policy support,

and responsible industry engagement. Going forward, improvements in agronomy and genetics, implementation of advanced conversion technologies (e.g., heterogeneous catalysis, continuous-flow, biorefinery models), integration with renewable energy systems, and rigorous lifecycle and sustainability assessments are central to transitioning Jatropha biodiesel from a niche option to a mainstream, environment-friendly fuel choice.

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References

- [1] Østergaard, P. A., Duic, N., Noorollahi, Y., & Kalogirou, S. (2022). Renewable energy for sustainable development. *Renewable Energy*, 200, 1642-1652. <https://doi.org/10.1016/j.renene.2021.07.111>
- [2] Cherwoo, L., Gupta, I., Flora, G., Verma, R., Kapil, M., Arya, S. K., & Ravindran, B. (2023). Biofuels an alternative to traditional fossil fuels: A comprehensive review. *Sustainable Energy Technologies and Assessments*, 60, 103530. <https://doi.org/10.1016/j.seta.2023.103530>
- [3] Singh, R., Gaur, A., Soni, P., Jain, R., Pant, G., Kumar, D., Kumar, G., Shamshuddin, S., Mubarak, N. M., Dehghani, M. H., Suhas, & Ansari, K. (2025). A review of biofuels and bioenergy production as a sustainable alternative: opportunities, challenges and future perspectives. *Journal of Environmental Health Science and Engineering*, 23(2), 23. <https://doi.org/10.1007/s40201-025-00946-0>
- [4] Emmanouilidou, E., Lazaridou, A., Mitkidou, S., & Kokkinos, N. C. (2024). A comparative study on biodiesel production from edible and non-edible biomasses. *Journal of Molecular Structure*, 1318, 139234. <https://doi.org/10.1016/j.molstruc.2024.139234>
- [5] Singh, D., Sharma, P., Soni, S. L., Inda, C. C., Pushpendra, K., & Jhalani, A. (2021). A comprehensive review of physicochemical properties, production process, performance and emissions characteristics of 2nd generation biodiesel feedstock: Jatropha curcas. *Fuel*, 285, 119110. <https://doi.org/10.1016/j.fuel.2020.119110>
- [6] Abdudeen, A., Subramaniapillai, S., Mohanavel, V., Asirvatham, S. J., & Pugazhendhi, A. (2023). Jatropha's Rapid Developments and Future Opportunities as a Renewable Source of Biofuel-A Review. *Energies*, 16(2), 828. <https://doi.org/10.3390/en16020828>
- [7] Shaah, M. A. H., Hossain, M. S., Allafi, F. A. S., Alsaedi, A., Ismail, N., Ab Kadir, M. O., & Ahmad,

- M. I. (2021). A review on non-edible oil as a potential feedstock for biodiesel. *RSC Advances*, *11*(40), 24825-24865. <https://doi.org/10.1039/D1RA04311K>
- [8] Cao, X., Wei, X., Shao, Y., Li, D., & Zhu, J. (2025). Jatropha curcas seed oil for possible human consumption: A toxicological assessment of its phorbol esters. *Toxicology Reports*, *14*, 101870. <https://doi.org/10.1016/j.toxrep.2024.10187>
- [9] Farouk, S. M., Tayeb, A. M., Abdel-Hamid, S. M. S., & Osman, R. M. (2024). Recent advances in transesterification for sustainable biodiesel production, challenges, and prospects: a comprehensive review. *Environmental Science and Pollution Research*, *31*(9), 12722-12747. <https://doi.org/10.1007/s11356-024-32027-4>
- [10] Otieno, S., Kengara, F., Kowenje, C., & Mokaya, R. (2024). Optimization of biodiesel production from Jatropha curcas seed oil using potassium-modified clinoptilolite as catalyst. *Inorganics*, *12*(4), 109. <https://doi.org/10.3390/inorganics12040109>
- [11] Tobío-Pérez, I., Lapuerta, M., Canoira, L., & Lalthazuala, S. (2025). Sustainable Production of Biodiesel Using Waste Jatropha curcas Shells as a Heterogeneous Catalyst. *ACS Omega*, *10*(24), 25192-25206. <https://doi.org/10.1021/acsomega.4c06782>
- [12] El Diwani, G., Attia, N. K., & Hawash, S. I. (2009). Development and evaluation of biodiesel fuel and by-products from Jatropha oil. *International Journal of Environmental Science & Technology*, *6*(2), 219-224. <https://doi.org/10.1007/BF0332762>
- [13] Jain, S., & Sharma, M. P. (2010). Prospects of biodiesel from Jatropha in India: A review. *Renewable and Sustainable Energy Reviews*, *14*(2), 763-771. <https://doi.org/10.1016/j.rser.2009.10.005>
- [14] Cao, T. T., Ho, X.-N., & Nguyen Duy, V. (2023). Biodiesel from Jatropha curcas seed oil: Status, perspectives, and challenges in Southeast Asia. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4589941>
- [15] Koh, M. Y., & Ghazi, T. I. M. (2011). A review of biodiesel production from Jatropha curcas L. oil. *Renewable and Sustainable Energy Reviews*, *15*(5), 2240-2251. <https://doi.org/10.1016/j.rser.2011.02.01>
- [16] Silitonga, A. S., Atabani, A. E., Mahlia, T. M. I., Masjuki, H. H., Badruddin, I. A., & Mekhilef, S. (2013). A global comparative review of biodiesel production from jatropha curcas using different homogeneous acid and alkaline catalysts: Study of physical and chemical properties of biodiesel. *Renewable and Sustainable Energy Reviews*, *24*, 514-533. <https://doi.org/10.1016/j.rser.2013.03.044>

- [17] Abdelwanis, F. M. T., Saleh, S. A., & Abdelaty, H. S. (2025). Jatropha: A Comprehensive Review of Its Potential as a Green Fuel. *Egyptian Journal of Chemistry*, 68(13), 57-68. <https://doi.org/10.21608/ejchem.2025.379145.11658>
- [18] Silitonga, A. S., Atabani, A. E., Mahlia, T. M. I., Masjuki, H. H., & Badruddin, I. A. (2011). A review on prospect of Jatropha curcas for biodiesel in Indonesia. *Renewable and Sustainable Energy Reviews*, 15(8), 3733-3756. <https://doi.org/10.1016/j.rser.2011.07.011>
- [19] Khalaf, H. H., Abdel-Fadeel, M. A., & El-Fadeel, M. A. (2023). Experimental Investigation of Different Extraction Methods for Producing Biofuel from Jatropha Seeds and Castor Seeds. *International Journal of Energy Research*, 2023, 1780536. <https://doi.org/10.1155/2023/1780536>
- [20] Yusuff, A. S., & Ewere, D. O. (2021). Parametric optimization of solvent extraction of Jatropha curcas seed oil using design of experiment and its quality characterization. *South African Journal of Chemical Engineering*, 35, 60-68. <https://doi.org/10.1016/j.sajce.2020.11.006>
- [21] Ntalikwa, J. W. (2021). Solvent Extraction of Jatropha Oil for Biodiesel Production: Effects of Solvent-to-Solid Ratio, Particle Size, Extraction Time, and Temperature. *International Journal of Chemical Engineering*, 2021, 9221168. <https://doi.org/10.1155/2021/9221168>
- [22] Mandari, V., & Devarai, S. K. (2022). Biodiesel Production Using Homogeneous, Heterogeneous, and Enzyme Catalysts via Transesterification and Esterification Reactions: A Critical Review. *BioEnergy Research*, 15(2), 935-961. <https://doi.org/10.1007/s12155-021-10333-w>
- [23] Efgan, K. M., Lina, H., Tuna, Ç. B., Bahçivanlar, B., & Ben Abdeljelil, B. (2023). Assessment of Homogeneous and Heterogeneous Catalysts in Transesterification Reaction: A Mini Review. *ChemBioEng Reviews*, 10(4), 412-422. <https://doi.org/10.1002/cben.202200021>
- [24] Gupta, V., & Singh, K. P. (2023). The impact of heterogeneous catalyst on biodiesel production; a review. *Materials Today: Proceedings*, 78, 364-371. <https://doi.org/10.1016/j.matpr.2022.10.175>
- [25] Nayab, R., Mumtaz, M. W., Baqar, Z., Hussain, N., Afifa, & Iqbal, H. M. N. (2022). Sustainable biodiesel production via catalytic and non-catalytic transesterification of feedstock materials - A review. *Fuel*, 328, 125254. <https://doi.org/10.1016/j.fuel.2022.125254>
- [26] Shashoug, W., & Özçimen, D. (2022). New Catalysts for Biodiesel Production under Supercritical Conditions of Alcohols: A Comprehensive Review. *ChemistrySelect*, 7(7), e202104459. <https://doi.org/10.1002/slct.202104459>
- [27] Monika, Pathak, V.V. & Banga, S (2025). A comprehensive analysis of refining technologies for

biodiesel purification. *Brazilian Journal of Chemical Engineering*. <https://doi.org/10.1007/s43153-025-00589-6>

[28] Neupane, D., Bhattarai, D., Ahmed, Z., Das, B., Pandey, S., Solomon, J.K.Q., Qin, R., & Adhikari, P. (2021). Growing Jatropha (*Jatropha curcas* L.) as a Potential Second-Generation Biodiesel Feedstock. *Inventions*, 6(4), 60. <https://doi.org/10.3390/inventions6040060>

[29] Alherbawi, M., Alamoudi, K., & Wang, H. (2021). Jatropha curcas for jet biofuel production: Current status and future prospects. *Renewable and Sustainable Energy Reviews*, 135, 110396. <https://doi.org/10.1016/j.rser.2020.110396>

[30] Prabhu, A., Venkata Ramanan, M., & Jayaprabakar, J. (2018). Production, properties and engine characteristics of Jatropha biodiesel – a review. *International Journal of Ambient Energy*, 41(4), 488–492. <https://doi.org/10.1080/01430750.2018.1557548>

[31] Zhang, K., & Tang, R. (2021). Environmental and techno-economic analyses of bio-jet fuel produced from jatropha and castor oilseeds in China. *The International Journal of Life Cycle Assessment*, 26(6), 1265-1280. <https://doi.org/10.1007/s11367-021-01914-0>

[32] Ceasar, S. A., & Ignacimuthu, S. (2011). Applications of biotechnology and biochemical engineering for the improvement of Jatropha and biodiesel. *Renewable and Sustainable Energy Reviews*, 15(9), 5176-5185. <https://doi.org/10.1016/j.rser.2011.07.039>

[33] Kashe, K., Kgathi, D. L., Murray-Hudson, M., & Mfundisi, K. B. (2018). 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. *Journal of Forestry Research*, 29(1), 1-12. <https://doi.org/10.1007/s11676-017-0460-1>

[34] Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., Simal-Gandara, J., & Khandaker, M. U. (2021). A review on environmental and socioeconomic perspectives of three promising biofuel plants *Jatropha curcas*, *Pongamia pinnata* and *Mesua ferrea*. *Biomass and Bioenergy*, 151, 106173. <https://doi.org/10.1016/j.biombioe.2021.106173>

[35] Pandey, V. C., Singh, K., Singh, J. S., Kumar, A., Singh, B., & Singh, R. P. (2012). *Jatropha curcas*: A potential biofuel plant for sustainable environmental development. *Renewable and Sustainable Energy Reviews*, 16(5), 2870-2883. <https://doi.org/10.1016/j.rser.2012.02.004>

[36] Tudge, S. J., & Purvis, A. (2021). The impacts of biofuel crops on local biodiversity: a global

- synthesis. *Biodiversity and Conservation*, 30(11), 2863-2883. <https://doi.org/10.1007/s10531-021-02232-5>
- [37] Kashe, K., Teketay, D., & Thupe, B. (2020). Invasiveness of biofuel crops: implications for energy research and policy in Botswana. *Development Southern Africa*, 37(6), 1004-1019. <https://doi.org/10.1080/03736245.2020.1768583>
- [38] Goh, B. H. H., Chong, C. T., Ong, H. C., Seljak, T., Kutrašnik, T., & Ng, J.-H. (2022). Strategies for fuel property enhancement for second-generation multi-feedstock biodiesel. *Fuel*, 315, 123178. <https://doi.org/10.1016/j.fuel.2022.123178>
- [39] Romero-Izquierdo, A. G., Gutiérrez-Antonio, C., Gómez-Castro, F. I., & Hernández, S. (2022). Synthesis and intensification of a biorefinery to produce renewable aviation fuel, biofuels, bioenergy and chemical products from *Jatropha curcas* fruit. *IET Renewable Power Generation*, 16(14), 2988-3008. <https://doi.org/10.1049/rpg2.1238>
- [40] El-Araby, R. (2024). Biofuel production: exploring renewable energy solutions for a greener future. *Biotechnology for Biofuels and Bioproducts*, 17(1), 129. <https://doi.org/10.1186/s13068-024-02571-9>
- [41] Rodrigues, A. C. C. (2021). Policy, regulation, development and future of biodiesel industry in Brazil: A systematic review. *Cleaner Engineering and Technology*, 4, 100197. <https://doi.org/10.1016/j.clet.2021.100197>
- [42] Shukla, R., & Mallick, S. (2023). Conflicting institutional mandates, biofuels, *Jatropha* in India. *Journal of Asian and African Studies*, 58(1), 3-19. <https://doi.org/10.1177/00219096221081767>
- [43] Yu, Z., & Zhang, F. (2025). Unlocking global climate mitigation potential with *jatropha* biodiesel production. *Journal of Cleaner Production*, 536, 147179. <https://doi.org/10.1016/j.jclepro.2025.147179>