**Sustainable Bio-diesel Production through Catalytic and Green Approaches: A Comprehensive Exploration of Eco-Friendly Pathways**

Saba Irum1, Saira Asif1\*, Chudary Sadam Hussain1, Zohaib Younas1, Iqra Tariq1, Anila Safdar1, Iqra Ilyas1, Muhammad Abbas Khan1, Aqeel Sultan1, Sajid Hussain1

Department of Botany, Pir Mehr Ali Shah-Arid Agriculture University Rawalpindi, 46000,

Pakistan

\*Corresponding author’s email: [sairaasif@uaar.edu.pk](mailto:sairaasif@uaar.edu.pk) ; afaqibotany555@gmail.com

**ABSTRACT**

Bio-diesel is methyl or ethyl ester of vegetable oil that can also produce by various seed oil they may be edible and non-edible toxic seed, algae, waste cooking oil and genetically modified plants. Because due to increase in the price of diesel and petrol, Production of bio-diesel is essential need of present era. bio-diesel is Eco-friendly and low in price that can be produced. Generally there are four methods used for the production of bio-diesel by using different catalyst and without catalyst.The aim of the paper is to make clear review of bio-diesel production with the help of various catalyst and without catalyst and specially focus on green and recyclable nano-catalysts.

**Keywords:** Bio-diesel,Dilution method,Micro-emulsion, Pyrolysis,Transesterification,

Catalyst, Nanoparticles

1. **INTRODUCTION**

Bio-diesel is otherwise called unsaturated fat methyl esters promoting reasonable bio-fuel innovations to address ecological supportability and environmentally friendly power requires areas of strength for a for long haul maintainable venture systems and an adaptable and practical roundabout economy (Rozina et al., 2022). By subbing inputs and expanding the level of inexhaustible and recyclable assets, the reconciliation of the roundabout economy to the spaces of course, manageability and strength will prompt a complete change of business. Albeit the round economy has picked up speed in established researchers, its hypothetical establishments and spot inside the possibility of maintainable development are still a matter of debate. (Schöggl et al., 2020). Bio-diesel is what might be compared to handle diesel fuel that is diesel comes from various natural sources and "green natural" oxygenated oil that is ester-based contained fats regular oils. Synthetically, its sorted mix of long chain unsaturated fat monoalkyl esters. It comprises plant subsidiaries, for example, palm oil, bush oil, soybean oil, bush oil safflower oil, sunflower oil, and canola oil. Vegetable oils or creature fats joined with alcohols within the sight of an impetus yield bio-diesel and glycerin. Methanol is liked for trans-esterification because of its sensible expense and accessibility (Verma and Sharma, 2016). The greatest choice for diesel fuel in diesel motors is bio-diesel .Bio-diesel is an unmistakable golden yellow fluid with the thickness of petro-diesel. It is more costly to deliver than gas, which is by all accounts the fundamental hindrance. Worldwide creation of creature fats and vegetable oils isn't sufficient to supplant the utilization of fluid non-renewable energy sources (up to 20-25%). The essential hindrances of bio-diesel are its low consistency, higher releases of nitrogen oxides, higher freezing, lower energy content and obscuring centers, lower power and coking of the injector engine speed, more over the top expense and extended engine wear (Yusuf and Athar, 2015). Functional impediments of methyl ester mixes remember fuel freezing issues for cold environments, diminished energy limit, and long haul fuel capacity issues because of debasement. Hydrocarbon fills by and large structure coatings on tank linings and hoses. These stores, which are relaxed by the bio-diesel blend, as a rule stop up fuel channels. This is a basic issue that can be immediately settled by legitimate channel upkeep once a bio-diesel mix is presented (Maheshwari et al., 2022).

Vegetable oil is an inexhaustible fuel elective for diesel motors. Be that as it may, because of its high consistency, vegetable oil can't be straight forwardly utilized as a fuel for diesel motors. Subsequently, there is an earnest need to diminish the thickness of vegetable oils. The thickness of vegetable oils can be decreased utilizing different strategies like mixing, broadly used to diminish the thickness and further develop the fuel properties of vegetable oils. (Mathiyazhagan et al., 2011). **Bio-diesel is a non-harmful environmentally friendly power source that is acquiring ubiquity because of its immediate application in existing motors without changes (Bhatia et al., 2021). It can possibly supplant diesel in motors. bio-diesel fueled motors have been verified to deliver low degrees of smoke and poisonous gases (Bharathiraja et al., 2014).**

Bio-diesel creation has as of late acquired ubiquity because of its ecological advantages. Heterogeneous impetuses have been liked over homogeneous impetuses for bio-diesel creation because of their proficient partition ventures for the two items and impetuses, end of the extinguishing system, and arrangement of conditions for a ceaseless creation framework. As per late examination, nanoparticles are generally utilized as a heterogeneous impetus for bio-diesel creation, and the utilization of heterogeneous nanocatalyst is expanding quickly. To accomplish profundity, the ongoing audit centers around the utilization of different heterogeneous nano-catalysts for bio-diesel creation (Narasimhan et al., 2021).

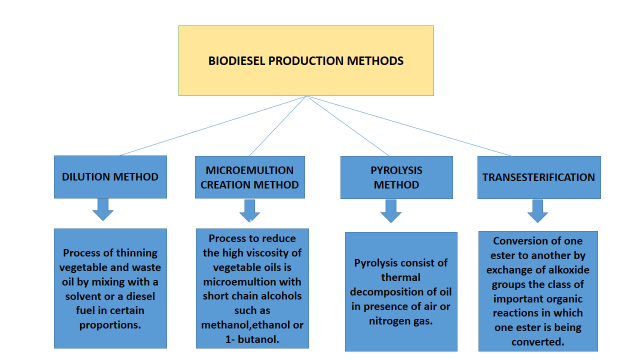


Figure-1 Different methods of bio-diesel production

**2. DILUTION METHOD** Dilution process; is a process of thinning

Weakening of waste oils and vegetable oil by consolidating them with a dissolved or methyl ester fuel in unambiguous extents. Vegetable oil or animal fat can be used as fuel in direct implantation engines since high calorific worth and can give sufficient power. In any case, in view of its lamentable properties, it can't be used in a DI engine without change. Elective fuel sources are directly blended in with customary petrol subsidiaries to avoid such issues. This kind of blending further creates fuel quality, diminishes oil subsidiary usage, etc making it the most advantageous method for utilizing elective powers, for example, bio-fuels. diesel mixes will have various proportions, for example, 10:1, 10:2, 10:3 and so on (Rajalingam et al., 2016). Oils used in the dilution method of bio-diesel production; peanut oil, rapeseed oil, sunflower oil and waste oils (Aktas et al., 2020).

**3.MICROEMULTION CREATION METHOD**

To reduce the viscosity of vegetable oil and fats, the micro-emulsion method is a potential solution to produce bio-diesel. Its micro emulsions have three components in suitable proportions: oil phase, liquid phase and the surfactant **(**Yadav et al., 2023).It is likewise characterized as a colloidal balance scattering of micro-structures of optically isotropic fluids with aspects by and large in the scope of 1-150 nm that immediately structure from two regularly immiscible fluids and at least one ionic or non-ionic amphiphiles. A cycle to decrease the high consistency of vegetable oils is micro-emulsion with short-chain alcohols like methanol, ethanol or 1-butanol. The 200 h-EMA test in like manner passed a micro-emulsion created utilizing a blend of soybean oil, cetane, 2-octanol and methanol in the going with extents: 52.7:1.0:33.3:13.3.This cycle is a thermodynamically consistent, isotropic liquid blend of oil, water, and surfactant. Its will handle the issue of oil consistency and other atomization properties (Rajalingam et al., 2016). For the most part, liquor is utilized to expand the unstable properties of the oil, which decreases smoke. Cetane number is expanded with alkyl nitrate. A micro-emulsion interaction is likewise utilized while infusing into the motor by means of a spout to accomplish great shower properties. In the event that miniature emulsified diesel fuel is utilized in a diesel motor, deficient ignition, carbon testimony and spout disappointment will happen (Parawira et al., 2010). The short-chain alcohol methyl and ethyl alcohol have the disadvantage that the microemulsified vegetable oil has lower heat values than the petroleum diesel fuel due to the presence of alcohol (Aktas et al., 2020).

1. **PYROLYSIS METHOD**

Pyrolysis is a strategy for warm decay of natural materials without any oxygen. It includes exposing the material to high temperatures in a controlled climate to separate it into its constituent parts. This cycle brings about the creation of strong buildup, fluid bio-oil, and a combination of gases. Pyrolysis requires expensive setup instrument used in this process known as pyrolyser for the distillation of various fractions of pyrolyzed materials (Yadav et al., 2023).

Here is an overall outline of the pyrolysis technique:

**4.1 Feed-stock Choice:** The initial step is to choose the fitting feed-stock, which can be any natural material like biomass, rural deposits, plastics, or even tires. The decision of feed-stock relies upon the ideal finished results and their particular properties.

**4.2 Warming for decomposition**: The chose feed-stock is then warmed in a pyrolysis reactor. The reactor can be a fixed-bed, fluidized-bed, or rotating furnace, contingent upon the scale and prerequisites of the cycle. The temperature is painstakingly controlled to guarantee the ideal response happens.

**4.3 Disintegration:** As the feed-stock is warmed, it goes through warm decay. The shortfall of oxygen forestalls burning and considers the breakdown of the material into its parts. The three fundamental results of pyrolysis are:

**a. Solid Residue :** Otherwise called roast or bio char, this is the strong carbon-rich material that remaining parts after pyrolysis. It very well may be utilized as a dirt correction or for different applications.

**b. Fluid Bio-oil**: This is a dull, gooey fluid made out of a great many natural mixtures. Bio-oil can be additionally handled and moved up to deliver energizes or synthetic substances.

**c. Vaporous Items**: Different gases, like methane, carbon monoxide, hydrogen, and unstable natural mixtures (VOCs), are delivered during pyrolysis. These gases can be gathered and utilized as a wellspring of energy or for different purposes.

**4.4 Product Assortment and Handling:** The subsequent strong buildup, fluid bio-oil, and gases are gathered and handled further. This might include steps like cooling, buildup, filtration, and cleaning to get the ideal finished results.

Pyrolysis offers a few benefits, like the development of significant items from squander materials, decrease of ozone harming substance discharges, and the potential for energy recuperation. It is utilized in different enterprises, including bioenergy, squander the board, and the development of sustainable fills and synthetic compounds (AKTAŞ et al., 2020).

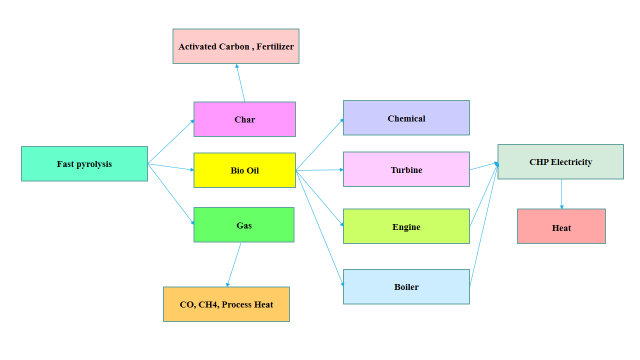
**4.5 Pyrolysis technique**

**4.5.1 Torrefaction (mild pyrolysis)**  It requires15-60 min, on 200–300°C temperature on>50 °C/min heat transfer speed and produce the primary products are Solid product, condensable liquid and non-condensable gases.

**4.5.2 Slow pyrolysis(conventional)**  It requires, 200−550 °C temperature on Very low  
(5–10 °C/min) heat transfer speed and produce the primary products are 20–50% Bio-oil  
25–35% Biochar 20–50% Gas.

**4.5.2.1 Intermediate pyrolysis)**  It requires, 10 min 300−450 °C on Medium,  
(200–300 °C/ min) heat transfer speed and produce the primary products are 35–50% Bio-oil  
25–40%Biochar 20–30% Gas.

**4.5.2.2 Fast/flash pyrolysis** It demands <2s on 300–1000 °C , and heat transfer speed is High,  
≈1000 °C/s and they produce the primary products that are 60–75% Bio-oil,10–25% Biochar  
 and 10–30% Gas **(**Hoang et al., 2021).

**** Figure.2 Fast pyrolysis

Pyrolysis is the warm decay of oil within the sight of air or nitrogen gas; likewise alluded to as warm breaking. Warm breaking is a cycle that, regardless of an impetus, changes over the complicated design of hydrocarbons into their most straightforward construction. The thickness and consistency of the oil will diminish because of this interaction. These two properties influence the atomization of the motor while involving vegetable oil as an elective fuel. On account of this cycle, the fuel can be utilized straightforwardly in diesel motors without alteration (Parawira, W. 2010). Alumina, zeolite, and red mud are ordinarily utilized as impetuses in the warm breaking process for bio-diesel creation. The warm breaking interaction will happen at 250°C to 350°C. Bio-diesel warm breaking hardware incorporates reactor with well being valve, release pipe, temperature pointer and different parts. The animal fat or vegetable oil to be changed over in methyl ester is set inside the reactor and power is applied to it. The animal fat or vegetable oil as of now disseminates and flows through the line to the condenser .The condenser cools the fume in the fluid and afterward the fluid is gathered in a measuring utencil called bio-diesel. Contrasted with other breaking strategies, the interaction is quicker, not so much contaminating but rather more productive (Rajalingam et al., 2016).

Biofuel creation from neem seeds have been assessed through non-reactant and synergist pyrolysis process. Co-Mo/Al2O3 and Ni-Mo/Al2O3 modern impetuses have been applied in overhauling cycle of pyrolysis oil to biofuel (Saidi et al., 2023).

**5.TRANSESTERIFICATION**

A class of significant natural responses wherein one ester is changed over into one more by trade of alkoxide gatherings. It is additionally characterized as the response of plant fatty oils with liquor to frame bio-diesel (monoalkaline ester) and glycerol. The most widely recognized strategy for delivering bio-diesel is the transesterification reaction (Etim et al., 2023).

**5.1 Transesterification strategy :**

A specific impetus is likewise utilized in this cycle to accelerate the response and work on the nature of the end result. The sum and sort of impetus not entirely set in stone by the substance of free unsaturated fats in the beginning oil. An expanded measure of free unsaturated fats is troublesome for the creation of bio-diesel, which brings about the development of cleanser and a lessening in the productivity of bio-diesel yield (Safaripour et al., 2023).

**5.1.1.Transesterification with essential catalyst:**

In this phase of the cycle, (KOH), (NaOH) and sodium methoxide are used as impulses. Sodium methoxide is the most productive impetus and simultaneously the most costly (Prabhakar et al., 2011; Nawaz et al., 2023). This is the response of liquor and oil within the sight of an essential impetus. Keep the response temperature between 500-600°C for best bio-diesel yield. The temperature of the reaction should be lower than the edge of bubbling over of methanol. In event that not, the methanol will be wasted in light of scattering. A blending cycle (1300 rpm) is utilized during the interaction to accelerate the response through powerful blending. The response requires roughly 1 hour to finish. bio-diesel and glycerol coming about because of the above response are isolated and the arrangement is set in a different dispersion community for 12 to 24 hours. The lower layer is glycerol and upper layer is bio-diesel ( Subramaniam et al., 2013).

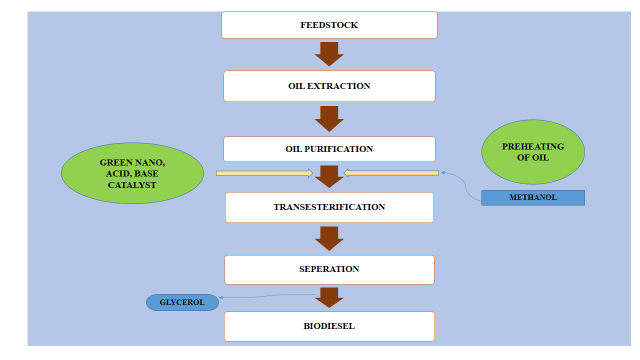
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Figure 3: Transesterification procedure

**5.1.2 Transesterification by Lipase catalyst**

Lipase-catalyzed transesterification is like basic transesterification and shifts with the catalyst dissolvable proportion, blending, and the impetus utilized in this transesterification is lipase. Lipases are known to work best with long chain greasy alcohols as opposed to short chain greasy alcohols.As a rule, the proficiency of methanol transesterification (methanolysis) for fatty substances in dissolvable and non-dissolvable frameworks is probably going to be lower than for ethanol (Bajaj et al., 2010). Lipase PS from Pseudomonas cepacia was chosen as the best organic impetus, and vinyl acetic acid derivation was utilized as the acyl contributor for the transesterification in isooctane (Parandi et al., 2023).

**6.CATALYSTS USE FOR PRODUCTION OF bio-diesel**

**** Figure.4 TypesofCatalyst use for production of bio-diesel

**6.1 Bio-diesel creation by homogeneous catalyst**

Esterification, ester hydrolysis, and transesterification have all been explored utilizing homogeneous impetuses. Corrosive and fundamental catalyst are two kinds of homogeneous impetuses. The most generally involved soluble homogeneous impetuses for the development of bio-diesel are NaOH, NaOCH3KOH, and KOCH3. According to studies, dissolvable driving forces can accelerate the transesterification reaction of low free unsaturated fat (FFA) oils a lot quicker than corrosive impetuses, while homogeneous corrosive impetuses are liked for high FFA or high water oils (Salimi and Hosseini, 2019).

The customary strategy for delivering bio-diesel from unadulterated vegetable oils is transesterification utilizing soluble impetuses. The best proportion of liquor to fatty oil was 6:1 for 98% bio-diesel yield. Corrosive impetuses can be utilized to make bio-diesel. less expensive unrefined components, notwithstanding the way that it requires more prominent temperatures, takes more time, and causes erosion (reactors, pipelines, vessels, and so forth) and other natural issues; the expense of item partition and cleaning makes it a less engaging interaction. Transesterification responses catalyzed by acids have a lower rate than ones catalyzed by soluble bases (Koh and Mohd Ghazi, 2011). To oppose corrosive erosion in these responses, costly gear is required. The inconveniences of homogeneous corrosive impetuses are that they require high centralization of corrosive impetuses and that the response happens at high temperatures (more than 100°C). Due to these conditions, ether is created, the oil is to some degree consumed, and the Notoriety yield is brought down (Gardy et al., 2019). There are anyway a few limitations, for instance, catalyst separation, shortcoming to water, FFAs in the feed and cleaning agent creation, and the need to kill the stimulus.

**6.2 Bio-diesel production by heterogeneous catalysts**

Heterogeneous impetuses have a few phenomenal properties for use as potential bio-diesel impetuses. They are non-destructive and effectively isolated from the items. They are additionally harmless to the ecosystem and can be recovered for reuse. A few reasonable heterogeneous impetuses ought to be created for the development of bio-diesel from modest feed-stocks. Co-precipitation, sol-gel auto-combustion, fume affidavit, electrochemical strategies and different methods are utilized to make heterogeneous impetuses.

**6.3 Transesterification by Strong base- catalyst**

Strong base impetuses have higher movement for feed-stocks with low FFA.Numerous strong impetuses have been utilized in the creation of bio-diesel. Alcoholic earth oxides, soluble earth metal oxides, basic earth oxides, hydrolithium, and antacid zeolites are instances of antacid earth impetuses. A few instances of the utilization of this impetus in the development of bio-diesel will be introduced in the accompanying segment. Strong base impetuses have a few burdens, particularly in business applications, for example, slow response rates, scattering of impetuses in the response medium, and impetus spillage. The dissolvability of the impetus in methanol diminishes as the foundation of the impetus increments. In light of this issue, more examination is expected to distinguish modest, dynamic impetuses for the transesterification response used to create bio-diesel (Gardy et al., 2019).

**6.4 Bio-diesel creation by Strong Acidic catalyst**

Strong corrosive impetuses have lower movement than strong base impetuses, requiring a higher response temperature and a more extended response time for transesterification. However, they are very steady. Strong corrosive impetuses show guarantee for handling FFA and water-rich feed-stocks (Gardy et al., 2019).

**6.5 Non-magnetic nanocatalysts**

The ability to recover and reuse strong impetuses empowers cheaper bio-diesel creation and the utilization of a decent bed reactor. Mass exchange obstruction is a commonplace issue in heterogeneous impetuses, making the response carve out opportunity to finish with OK effectiveness. In view of these downsides, the utilization of mass strong impetuses in modern applications is restricted. The work to foster an impetus with a little molecule size and a huge dynamic surface limits mass exchange obstruction and assists with expanding bio-diesel creation yield (Akia et al., 2014). The improvement of nanocatalysts and decreased molecule size at the nanoscale are two solutions to the issue of mass exchange obstruction in impetuses. The specific surface area of nanocatalysts is extensive (more prominent than 50 m2 g1). Nanocatalysts have an extraordinary number of synergist destinations and therefore high movement because of their colossal surface region, which prompts their boundless application in bio-fuel age (Bankovic-Ilic et al., 2017). Molina utilized ZnO nanorods to deliver bio-diesel from olive oil and produce (94.8% yield) from ZnO nanorods (Akia et al., 2014). Madhuvilakku and Piraman (2013) made bio-diesel from palm oil using ZnO and TiO2-ZnO nanocatalysts. Right when Ti particles were brought into the zinc oxide matrix, they made deserts in the oxide structure, which propels reactant development. Mesua ferrea oil used as feed-stock for bio-diesel production stimulus with a Co/ZnO nanocatalyst. At a methanol/oil extent of 9 at 60 °C for 3 hours and 2.5 wt% impetuses, they created a greatest bio-diesel creation of 98.03%. By utilization reaction surface way to deal with streamline the bio-diesel creation process over a NaAlO2/c-Al2O3 nanocatalyst best yield 97.65% was recorded (Zhang et al., 2020 : Borah et al., 2019).

Baskar et al., (2018) utilized a Ni-doped ZnO nanocatalyst to make bio-diesel with a high free unsaturated fat substance from castor oil. With M/O of 8, 11% wt.% impetus for an hour at 55 °C, the reaction surface technique (RSM) anticipated 95.20%. Multiple times the impetus may be reused. As recently expressed, base impetuses are more dynamic in the age of bio-diesel than corrosive impetuses and thus more fit to the cycle. Accordingly, the essential impetuses have been completely analyzed. KOH/Ca12Al14O33-C nanocatalyst for canola oil bio-diesel creation (Nayebzadeh et al., 2019).

Obadiah et al. (2012) worked on the course of transesterification of Pongamia oil by calcined Mg-Al hydrotalcite to obtain 90.8% bio-diesel. Wen et al. (2010) made a KF/CaO nanocatalyst and used it to make bio-diesel from Chinese fat seed oil. The yield 96.8% after 2.5 hours at 65 °C.

Deng et al. (2011) portrayed the utilization of hydrotalcite with a Mg/Al molar extent of 3:1 as a promising stimulus for conveying bio-diesel from Jatropha oil (95.2% yield).under ultrasonic settings.The creation of bio-diesel from Karanja and Jatropha oils using a Li/CaO nanocatalyst and got practically 100 percent yields for Karanja and Jatropha oil transesterifications following 1 hour and 2 hours, independently (Kaur and Ali, (2011).

The nano CaO in various designs was analyzed, and it was found that the more imperative surface area, little crystallite size, and flaws show huge returns of transesterification of soybean oil. Wang and Yang similarly focused on the use of nano MgO in the collecting of bio-diesel from soybean oil at both supercritical and subcritical temperatures (Wang and Yang, 2007).

The potassium doped zeolite imidazolate structure is used in the transesterification cycle to convey bio-diesel from soybean oil 98% yield produce (Saeedi et al., 2016). Chelladurai and Rajamanickam proposed using nano-Zn-Mg-Al hydrotalcite as solid base stimuli for the transesterification of neem oil to make bio-diesel (Chelladurai and Rajamanickam, 2014).

Dias et al. have definite using Mg/Al oxides made from Jatropha oil with a bio-diesel yield of 95.2% (Dias et al., 2012). Manivannan and Karthikeyan depicted the utilization of Mg-Al nano hydrotalcite in the methanolysis of neem oil produce 84% yield (Manivannan and Karthikeyan,2013).

Table 1. Non-magnetic nano-catalysts used for bio-diesel production

|  |  |  |
| --- | --- | --- |
| **Non-magnetic nanocatalysts** | **feed-stock**  **For bio-diesel production** | **References** |
| **1)**  ZnO | Olive oils | (Akia et al., 2014). |
| **2)**  ZnO and TiO2-ZnO | Palm oil | (Amini et al., Madhuvilakku and Piraman, 2013) |
| **3)** Co/ZnO | Mesua ferrea oil | (Borah et al., 2019) |
| **4)** Ni-doped ZnO | Castor oil | (Baskar et al., 2018) |
| **5)** OH/Ca12Al14O33-C | Canola oil | (Nayebzadeh et al., 2019) |
| **6)** Mg-Al hydrotalcite | Pongamia oil | (Obadiah et al., 2012) |
| **7)** KF/CaO | Chinese tallow seed oil. | (Wen et al., 2010) |
| **8)** Al/ Mg | Jatropha oil | (Deng et al., 2011) |
| **9)** Li/ Ca O | Karanja and Jatropha oils | (Kaur and Ali, 2011) |
| **10)**  Ca O | Soybean oil | (Reddy et al., 2006). |
| **11)** Mg O | Soybean oil | (Wang and Yang, 2007). |
| **12)**  Nano zeolites | Microalgae oil | (de Vasconcellos et al., 2018) |
| **13)** K doped zeolite | Soybean oil | (Saeedi et al., 2016). |
| 1. Zn-Mg-Al hydrotalcite | Neem oil | (Chelladurai and Rajamanickam, 2014). |
| **15)** Mg/Al oxides | Jatropha oil | (Dias et al., 2012). |
| **16)** Mg-Al nano hydrotalcite | Neem oil | (Manivannan and Karthikeyan, 2013). |

**6.6 Magnetic nanocatalysts**

In past, nano-magnetic impetuses were utilized in bio-diesel union and are expected to be appropriate for bio-diesel creation from minimal expense feed-stocks.Make alluring nano-catalysts of NixZn1xFe2O4 for methyl ester association through neem oil esterification. Catalysts were made using (Zn(NO3)2 6H2O), (Ni(NO3)2 6H2O), (Fe(NO3)3 9H2O), (CH3OH), and (C6H14N4O2) (Merck, Germany). The nanocatalysts were depicted by different tests (Farokhi et al.,2023). CdO and TiO nanocatalysts maintained by appealing material were used in the esterification, transesterification, and hydrolysis of soybean oil (Alves et al., 2014). At 200 °C, following 1 hour of esterification with attractive SnO, a 84% yield was gotten. The impetus was used multiple times with no movement misfortune. Hu et al. (201l) portrayed use of Stillingia oil in the combination of bio-diesel using KF/CaO-Fe3O4. The most noteworthy movement was tracked down following 3 hours of calcining at 600 °C with 25 wt% KF/5 wt% Fe3O4. Feyzi and co. integrated bio-diesel from sunflower oil utilizing a Cs/Al/Fe3O4 nanocatalyst. The best impetus was exceptionally dynamic, creating 94.8% bio-diesel. As per the models provided, high surface region nanocatalysts. Feyzi et al. (2013) : Tang et al. (2012) futrher research detailed the reactant action of an attractive Ca/Al/Fe3O4 composite for bio-diesel combination with a bio-diesel yield of 98.71% by stacking calcium aluminate onto Fe3O4 nanoparticles. Dantes et al. joined appealing Ni0.5Zn0.5Fe2O4 and used it in methyl and ethyl bio-diesel creating processes from soybean oil. 99.5% yield produced (Dantes et al., 2020).

Bio-diesel delivered from chicken fat using a CaO/CuFe2O4 nanocatalyst made 94.52% yield of bio-diesel (Seffati et al., 2019). Feyzi and Norouzi, (2016) definite the mix of an appealing Ca/Fe3O4@SiO2 nano-catalyst for bio-diesel age utilizing a mix of sol-gel and early wetness impregnation techniques. Under ideal circumstances, the nanocatalyst created 97% bio-diesel.

Table.2 Magnetic nanocatalysts for bio-diesel production

|  |  |  |
| --- | --- | --- |
| **Magnetic nanocatalysts** | **feed-stock For bio-diesel creation** | **References** |
| **1)**Cd /Tin/ FeO | Soybean oil | Mokhatr et al (2020) |
| **2)**  NixZn1−xFe2O4 | Neem oil | Farokhi etal (2023) |
| **3)** Cd and TiO | Soybean oil | Alves et al.,(2014 ) |
| **4)** Fe3O4/ CaO | Date palm seed oil. | Ali et al., (2017) |
| **5)**  KF/CaO-Fe3O4. | Stillingia oil | Hu et al., (201l) |
| **6)**  Al / Cs /Fe3O4 | Sun flower oil | Feyzi et al.,( 2013) |
| **7)**  Ni0.5Zn0.5Fe2O4 | soybean oil | (Dantas et al., 2020) |
| **8)** CaO/CuFe2O4. | chicken fat | (Seffati et al., 2019) |

**6.7 Hetrogenous base catalyst**

The utilization of heterogeneous impetuses in consistent cycles was proposed to be practical. Heterogeneous biomass impetuses are both earth and financially practical, yet they are underutilized. Aransiola et al., (2014) discussed the successfully make bio-diesel, concentrates on heterogeneous base impetuses for oil transesterification were directed. Thirteen metal oxides including calcium, barium, magnesium, or lanthanum were made as impetuses. CaTiO3, CaMnO3, Ca2Fe2O5, CaZrO3, and CaO-CeO2 calcium-containing impetuses showed solid movement and methyl ester yields of more than 90%. Synergist sturdiness studies were likewise performed by rehashing the transesterification response with the recuperated calcium-containing impetuses from the earlier response blend. CaZrO3 and CaO-CeO2 have been found to have extraordinary perseverance and the possibility to be utilized as heterogeneous base impetuses in bio-diesel producing processes (Kawashima et al., 2008).

**6.8 Heterogeneous catalyst**

It is surely known that heterogeneous impetuses limit pointless handling costs related with homogeneous catalysis as well as different toxin creation. Heterogeneous impetuses likewise consider fast reusing and reuse, bringing about a minimal expense green cycle (Endalew et al., 2011). Dynamic particles can be united and caught on or in strong help pores like silica, alumina, or ceria in heterogeneous impetuses. In synthetic responses like Michael Buildup, isomerization, Buildup, oxidation, and transesterification, dissolvable base earth metal oxides, metal advancement oxides, mixed metal oxides, particle trade tars, and antacid metal mixtures are used. Due to its solvency, SrO (strontium oxide) doesn't break down in methanol and can keep up to 10 patterns of productivity (Hosseini et al., 2022).

The work of synergist squander materials can help with the goal of some garbage removal challenges, and the worth added materials can support different cycles. Scientists have created natural waste-based strong impetuses, for example, plantain stripping, wood, case shells, and palm. As per studies, banana strips utilized as strong waste impetuses produce potassium and sodium oxides . By drying banana strips in a hot-air oven, at 80 °C for 48 hours and calcining it at 700 °C for 4 hours. a stimulus was made (Betiku et al., 2016).

**6.9 Homogeneous catalyst**

Homogeneous impetuses, both acidic and essential, are normally used in bio-diesel creation. The movement of corrosive impetuses is lower than that of base impetuses. The corrosive impetus turns out to be more powerful when the FFA focus in the oil surpasses 1%. Cleanser frothing is many times forestalled by corrosive impetuses. Because of the acids catalyzing the esterification of FFAs into Notoriety, bio-diesel creation increments. Since corrosive catalyzed responses are more slow than base-catalyzed responses, they require high temperatures and tensions. (Refaat, 2010). The opportunities for bio-diesel blend of acidic profound eutectic solvents (DESs) was likewise contemplated. It has been exhibited that these DESs convert over 90% of bio-diesel. The productivity with which different DESs convert bio-diesel. Since FFAs respond with a soluble impetus to create cleanser, their virtue is essential for basic impetuses. This procedure limits the response and influences the bio-diesel yield.

Table 3. The contrast among homogeneous and heterogeneouscatalyst.

|  |  |  |
| --- | --- | --- |
| **Properties** | Heterogeneous catalyst | **Homogeneous catalyst** |
| **Reaction Rate** | Conversion rate is moderate. | Quick and huge change |
| **Reuseability of Catalyst** | Yes | Not |
| **After Treatment** | It is feasible to recover | No impetus recuperation ought to be killed by redirecting waste synthetic substances |
| **Methodology** | Constant fixed-bed activity is conceivable. | Continuous approach is utilized rarely. |
| **Free Fatty Acids/ Presence of H2O/** | Non-Sensitive | Sensitive |

#### Various explores have recommended that salt reactant transesterification can be directed assuming the FFA level of the feed-stock is under 1% and all parts are essentially anhydrous. Table 1 analyzes homogeneous and heterogeneous impetuses rapidly. At comparable low temperature and strain, the more prominent ester change is accomplished. It likewise demands less time while utilizing a straightforward catalyze, which impressively saves process costs. KOH and NaOH, for instance, are more affordable than metal alkoxides and have quicker responses than Na and K meth-oxides.

#### Utilization of profound eutectic solvents (DESs) underway of methyl ester

#### DESs, similar to Ionic Fluids, assume an essential part in the assembling of bio-diesel (ILs). DES is an ILs partner with additional harmless to the ecosystem characteristics like solid warm and substance strength, non-destructiveness, and insignificant smolder pressure (Haider et al., 2021). To make DESs, the hydrogen bond promoter and acceptor partake in a predestined molar extent. The resulting DESs have relaxing centers lower than either the provider or acceptor of the hydrogen bond. The production of hydrogen connections between the giver and acceptor of the hydrogen bond brings about the lower liquefying point of DESs. Fashioner solvents are those that might be modified to explicit purposes by consolidating a few kinds of hydrogen bond contributor and acceptor. DESs are utilized as impetuses in both single-step and multi-step processes (Mamtani et al., 2021). They may likewise further develop impetus partition and end result decontamination by diminishing side responses i.e. saponification (Sander et al., 2018). A few DESs can eliminate glycerine and any extra impetus from a mix (Kada pure et al., 2017). DESs have actually acquired favor as a force in countless purposes. Since DESs are made from a legitimate molar extent of hydrogen bond giver and acceptor. DESs are in like manner utilized as a catalyst in the transesterification reaction for bio-diesel age. In the nonappearance and presence of DES, bio-diesel produced from rapeseed oil and calcined CaO had a Notoriety change of 86.9% and 94.8.0%, separately (Huang et al., 2013). CaO that has not been calcined is ineffective (4.0% yield), however when blended in with DES, the ester yield increments to 91.9%. (Reyero et al., 2014). DESs can work as an impetus, dissolvable advertiser, and co-dissolvable in transesterification/esterification processes. Since Zn2Cl5 is somewhat acidic, DES, ChCl: ZnCl2 (1:2) brings about restricted change. DESs are created in two phases: esterification of crude petrol palms with high FFA content, followed by transesterification including KOH as an impulse (Hayyan et al., 2013).

#### Biocatalyst

#### Biocatalysts are a kind of heterogeneous impetus utilized for enzymatic transesterification of bio-diesel, yet the proteins are costly and unequipped for giving the level of response finishing expected to meet ASTM fuel specifics. Moreover, as a secondary effect, glycerin influences the impetus .The basic obstruction of using bio-diesel is its high creation cost, which still up in the air by regular substance costs (vegetable oils, stimuli, and alcohol . Compounds are furthermore used in the advancement of bio-diesel; for example, lipases got from various microorganisms go about as catalysts (Ranganathan et al., 2008). The biocatalyst gives higher bio-diesel change at moderate temperature, strain, and pH.In contrast with soluble base or corrosive impetuses in enzymatic bio-diesel creation, the finished results contain next to zero lingering or cleanser, bringing about excellent glycerol creation. The biocatalyst is viable with acidic feed-stocks. The primary drawback of bio-catalysts is that they require a high fixation and have a long response time. The partition of the chemical from the end result after the response is troublesome, adding tremendous expense to bio-diesel creation. Maheswari and partners. 2022. Compound catalyzed and biomass-inferred impetus responses are both efficient and econ-accommodating. On account of its high virtue item and simplicity of detachment from the side-effect, glycerol, enzymatic transesterification including lipases has as of late acquired fame for bio-diesel creation. Immobilized lipases and entire cells might diminish in general expenses while presenting less downstream handling issues in bio-diesel creation (Bizen et al., 2010). The drawbacks of the lipase-catalyzed process incorporate high catalyst costs (because of partition and cleansing expenses) and unfortunate compound securit (Marchetti et al., 2007).

#### Green nanotechnology for methyl ester

#### Rengasamy et al. (2016), announced the transformation of castor oil to methyl ester utilizing iron nanoparticles intervened by castor leaf. A cycle interceded by castor bean (*Ricinus communis*) leaf extricate was created with the combination of iron nano-catalyst. Dawood et al. (2022) investigation on bio-diesel amalgamation from non-eatable oil from Prunus bokhariensis seeds utilizing green silver oxide nano-catalyst. Natural and recycleable silver oxide nanoparticles blended from *Monotheca buxifolia* leaf extricate. Another research investigation by Ahmad et al. (2022), likewise dealt with the development of methyl ester of *Zanthoxylum armatum* seed oil utilizing a green silver oxide nanocatalyst from the watery concentrate of Silybum marianum leaves.Saman et al make bio-diesel from *Ziziphus mauritiana* seed oil utilizing MgO nanocatalyst blended with leaf concentrate of a similar plant (Saman et al., 2021). ffectively produce bio-diesel from grape buildup and seed oil utilizing MnO2 utilizing oregano nanoparticle (Stegarescu et al., 2020). Alsaiari et al. (2023) integrated green and recycleable Bi2O3 nanoparticles for maintainable methyl ester creation through film reactor, a profoundly responsive and recyclable bismuth oxide nano-catalyst got from *Euphorbia royealeana* leaf extricate by a natural strategy for the feasible union of bio-fuels from exceptionally proficient Pot sativa seed oil.

#### *Terminalia chebula* is another green hotspot for the combination of copper oxide nanoparticles and as an unrefined substance for the creation of methyl ester and its application to diesel motors. CuO NPs were orchestrated by means of an answer burning course utilizing T. chebula leaf remove as a lessening burning specialist. CuO NPs were effectively utilized for the blend of bio-diesel utilizing *T chebula* oil as unrefined substance by changing the response boundaries (Yatish et al., 2021). Combination of bio-diesel from *Toona ciliata* seed oil utilizing barium oxide nano impetus based film reactor. Green combined barium oxide nanoparticles for one-step transesterification of bio-diesel creation utilizing film innovation followed by portrayal of the pre-arranged impetus utilizing imaginative methods (Hanif et al., 2022). Ahmad et al additionally chipped away creation of bio-diesel from new and non-palatable *Chamaerops humilis* seed oil utilizing recyclable cobalt oxide nanoparticles. Modest and green cobalt oxide nanocatalyst were incorporated with *Galium boreale* leaf separate for catalyzed transesterification. Ahmad et al. (2021) discussed the transformation of *Citrus aurantium squander* seed oil to methyl ester utilizing reuseable zirconia nanocatalyst. Zirconia nanoparticles blended with fluid concentrate of *Alternanthera pungens* leaves.

#### Orchestrated calcium titanate nanoparticles (CaTiO3 NPs) by arrangement burning blend (SCS) utilizing *Ochrocarpus longifolius* leaf extricate as an original fuel. CaTiO3 nanoparticles were effectively used in the combination of bio-diesel from dairy squander ooze as a heterogeneous base impetus (Yatish et al., 2020). (Sivanesh et al., 2022) Orchestrated green CeO2 nanoparticles for the planning of bio-diesel from *Annona squamosa* oil. Eco-accommodating cerium nano-oxide was orchestrated by a basic and proficient arrangement ignition course utilizing another fluid concentrate of *Brahma Kamal* leaves. Yadav et al. (2019) directed an investigation on the readiness of green burning of Ag-doped ZnO nanoparticles (NPs) utilizing turmeric root remove as fuel. Combination of bio-diesel from *Terminalia belerica* oil with Ag ZnO as nanocatalyst was concentrate (Jan et al., 2022). Dawood et al. (2021) worked on bio-diesel production on the seed oil of milk thistle by using green nanoparticles of ZnO that were produced by using same plant extract. Dawood et al work on bio-diesel creation from non-consumable *Brachychiton populneus* oil in presence of nickel oxide nanoparticle. Union of nickel oxide nanocatalyst utilizing Ficus flexible watery plastic concentrate.

# Ahmad et al. (2022) discussed concentrate on methyl ester union from seed oil of *Monotheca buxifolia* utilizing of calcium oxide green nano-particles combined with watery leaves concentrate of *Boerhavia procumbens*. Rasheed et al. (2022) produce bio-diesel from squander vegetable cooking oil utilizing green blended CaO nanoparticles, as an impetus. The created CaO nanoparticles were fundamentally and morphologically dissected utilizing a few portrayal methods. Utilizing new non-consumable oil of Diospyros malabarica (Malabar Black) by utilizing green nano-catalyst of Cadmium oxide (CdO2) ready from leaf concentrate of *Buxus papillosa* by means of natural strategy followed by in situ wet impregnation approach (Arshad et al., 2023). Munir et al., (2023) directed investigate *Carthamus lanatus* seed oil as unique, non-palatable and squander feed-stock was explored for creating methyl ester utilizing cobalt tungsten stacked decreased (CoWO3@rGO) graphene oxide as , green and unique recyclable impetuses. Many advanced techniques were utilized in portrayal of Green nano-catalyst detail given in table.The creation of Popularity was affirmed by utilizing gas chromatography-mass spectroscopy (GC-MS), atomic attractive resonance and Fourier change infrared spectroscopy strategies.

Table.4 Green synthesized Nanoparticles for bio-diesel production

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Green**  **synthesized Nanoparticles** | **Plant used**  **For synthesis of NPs** | **feed-stock**  **For bio-diesel production** | **Characterization**  **of NPs** | **References** |
| **1) Fe** | Ricinus communis | Ricinus communis  seed oil | (UV-visible), (FTIR), (XRD), X-ray (XPS), (SEM), (EDX) and (TEM). | Rengasamy, et al 2016 |
| **2) Ag2 O** | *Monotheca buxifolia* (Falc.)  Silybum marianum | *Prunus bokhariensis*  seed oil  *Zanthoxylum armatum* seed oil | (EDX, FT-IR, SEM and XRD)  (XRD),(SEM), (EDX), (FTIR) and (NMR) | Dawood et al 2022  Ahmad et al 2022 |
| **3) Mg O** | *Ziziphus mauritiana* | *Ziziphus mauritiana* seed oil | (XRD), UV–Vis  (TEM), (SEM),  and (EDX). | Saman et al 2021 |
| **4) MnO2** | plant extracts  oregano extracts | grape residue and seeds oil. | TEM, XRD, BET, XPS, *and* VSM | Stegarescu, et al 2020 |
| **5) Bi2O3** | *Euphorbia royealeana* | *Cannabis sativa*  seed oil | FT-IR (XRD), Microscopy (SEM), X-Ray and (EDX) | Alsaiari, et al 2023 |
| **6) Cu O** | *Terminalia chebula* | *Terminalia* chebula seed oil | XRD, FTIR, FESEM, BET,  and [Zeta potential](https://www.sciencedirect.com/topics/engineering/zeta-potential" \o "Learn more about Zeta potential from ScienceDirect's AI-generated Topic Pages) | Yatish, et al 2021 |
| **7) Ba O** | *Toona ciliata* | *Toona ciliate*  seed oil | (SEM), (EDX), (FTIR) (XRD) and (TGA) | Hanif et al 2022 |
| **8) Co O** | Galium boreale | Chamaerops humilis seed oil | FTIR, XRD, TGA, SEM and EDX | Ahmad et al 2022 |
| **9) Zr O** | Alternanthera pungens | *Citrus aurantium*  seed oil | (SEM), X-Ray (XRD) (EDX) (FTIR),(GC/MS), and (NMR). | Ahmad et al 2021 |
| **10)CaTiO3** | Ochrocarpus longifolius | dairy waste scum oil (DWSO) | [SEM](https://www.sciencedirect.com/topics/engineering/scanning-electron-microscope" \o "Learn more about SEM from ScienceDirect's AI-generated Topic Pages), XRD, [TEM](https://www.sciencedirect.com/topics/engineering/electron-microscope" \o "Learn more about TEM from ScienceDirect's AI-generated Topic Pages), BET,CO2-TPD and FT-IR | Yatish, et al 2022 |
| **11) CeO2** | Brahma Kamal leaf extract | *Annona squamosa*  seed oil | Photoluminescence  FT-IR (XRD) (UV)  (EDX) ([SEM](https://www.sciencedirect.com/topics/engineering/scanning-electron-microscope" \o "Learn more about SEM from ScienceDirect's AI-generated Topic Pages)) and ([TEM](https://www.sciencedirect.com/topics/engineering/electron-microscope" \o "Learn more about TEM from ScienceDirect's AI-generated Topic Pages)) | Sivanesh et al 2022 |
| **12**) **Ag-doped ZnO** | Turmeric root extract  Silybum marianum | *Terminalia belerica* seed oil  Silybum marianum | XRD , SEM , TEM, XPS , (UV–Vis), and FTIR  XRD , SEM | Yadav et al 2019  Jan et al 2022 |
| **13) Ni O** | Ficus elastic. latex extract | (Brachychiton populneus) seed oil | (FTIR)  (EDX (XRD) and (SEM) | Dawood et al 2021 |
| **14). Ca O** | Boerhavia procumbens.  aqueous leaves extract  aqueous leaves extract | Monotheca buxifolia seed oil  waste vegetable cooking oil | (XRD), (SEM) and  (EDX)  (XRD), (SEM) and  (EDX) | Ahmad,etal 2022  Rasheed,etal 2022 |
| **15) CdO2** | leaf extract of Buxus papillosa | Diospyros malabarica (Malabar Ebony) seed oil | (SEM), (EDX), thermo-gravimetric analysis and (XRD) | Arshad et al 2023 |
| **16) CoWO3** | aqueous leaves extract | Carthamus lanatus L. seed oil | (XRD) (SEM), (FT-IR) and (EDX). | Mamoona etal  2023 |

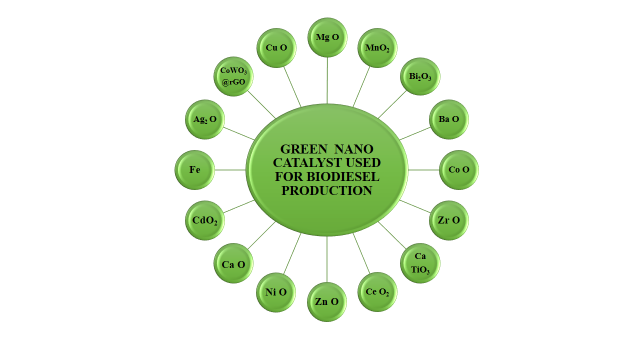


Figure 5. Green nano catalyst used for bio-diesel production

1. **Catalyst Free bio-diesel Creation Strategies**

**10.1 Direct supercritical transesterification (DST) process.**

The strategy for delivering bio-diesel without an impetus is supercritical transesterification (DST). Supercritical transesterification is a moderately new procedure that commitments benefits over conventional transesterification techniques, such as quicker response times, impetus free activity, and higher immaculateness of the end result. Critically, while high bio-diesel yields have been accounted for utilizing (DST) processes, these cycles are depicted by high energy usage and compound costs. The high energy usage is a result of the introduction at (350 °C) and high strain (>20 MPa) conditions, and the high compound amount is a direct result of the need of colossal masses of alcohol reactant, for example DST methyl ester (Mathur, 2008).

**10.2 Incorporated subcritical lipid hydrolysis and supercritical esterification (ISHSE) process.**

A consolidated (ISHSE) process produces bio-diesel without the use of a driving force. This is a direct result of the ISHSE cycle, which combines a basic subcritical lipid hydrolysis with a supercritical esterification reaction, which requires a lower methanol to oil molar extent of 20:1, lower reaction temperatures going from 250°C to 270°C, and lower pressures. going from 7 MPa to 8.1 MPa contrasted with elective impetus free DST bio-diesel creation processes (Okoro et al., 2018).

**CONCLUSION**

Bio-diesel arose as a likely elective fuel to decrease the reliance on non-renewable energy sources. It won't just diminish anthropogenic outflows yet additionally can possibly support the neighborhood economy. A few variables ought to be consider in the creation of bio-diesel like expense, property, creation technique, required hardware, and so forth, the transesterification cycle will give a superior fuel quality and yield productivity, it additionally requires no convoluted exceptional gear. The glycerol will get as a bi result of an interaction. It very well may be utilized for a few other required applications which will diminish the general creation cost. As a result of the above reasons the transesterification cycle can be the preferable bio-diesel creation process over others and impetus likewise assume significant part creation of bio-diesel. Green and recyclable impetus are more effective then other essential impetus they produce best yield of bio-diesel.

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