# SUSTAINABLE BIOFUEL PRODUCTION FROM WATER HYACINTH-A REVIEW

[1] M. S. N. SATYA PRASAD, [2] Dr. K. PRASADA RAO, [3] CH. LOKESH, [4] CH. RAJESH.
[1, 3, 4] UG Students, Department of Mechanical Engineering, NRIIT, Agiripalli, Vijayawada, AP-India-521212
[2] Professor, Department of Mechanical Engineering, NRIIT, Agiripalli, Vijayawada, AP-India-521212

satyaprasad1508@gmail.com, kancherlakp@gmail.com,
lokeshch531@gmail.com,rajeshchalamalapalli69@gmail.com

## ABSTRACT:

Fossil fuels such as coal, petroleum, and natural gas remain the primary energy sources for modern society; however, they are finite and rapidly depleting. To address this challenge, researchers are exploring renewable and sustainable alternatives, with biodiesel emerging as a promising solution. Therefore, attention has shifted to underutilized biomass like water hyacinth a fast-growing aquatic weed known for its high lignocellulosic content and widespread availability. Water hyacinth poses ecological threats by invading freshwater ecosystems but also offers potential as a bioenergy source. This study focuses on producing biodiesel from water hyacinth. Utilizing water hyacinth for biofuel not only helps reduce dependency on fossil fuels but also addresses environmental issues like water pollution and invasive plant management. Thus, water hyacinth serves as a sustainable, low-cost, and eco-friendly feedstock with multi-dimensional benefits in energy production and environmental protection.

**KEYWORDS:** Water hyacinth, Fossil fuels, Renewable energy, Bio fuel, ecological, bio energy,

## I. INTRODUCTION

Water hyacinth is a free-floating perennial aquatic plant native to the Amazon basin of South America. It is well known for its rapid growth and ability to spread across water bodies, forming dense mats that cover the surface. Although it is considered one of the world's most invasive aquatic weeds, water hyacinth also has significant ecological, social, and economic importance. The plant is characterized by its glossy, rounded leaves, inflated petioles, and attractive violet flowers. Its ability to reproduce both sexually (through seeds) and vegetative enables it to multiply at an alarming rate. In favorable tropical and subtropical climates, water hyacinth can double its biomass in just 7–12 days. While it poses serious challenges to aquatic ecosystems—such as blocking sunlight penetration, depleting dissolved oxygen, hindering navigation, and affecting fisheries—it also offers potential benefits. Recent studies highlight its usefulness in wastewater treatment, biogas production, composting, animal fodder, handicrafts, and even bioethanol generation. Thus, water hyacinth is often referred to as a "problem plant with hidden potential" Water hyacinth, an invasive aquatic plant, presents a dual opportunity for biofuel production as a sustainable energy source and a method for environmental cleanup. Its high lignocellulosic content, particularly cellulose and hemicellulose, can be converted into sugars through pre- treatment and enzymatic hydrolysis, which are then fermented into bioethanol. Alternatively, it can be used to extract oils for bio-diesel production via, offering environmental benefits like reduced fossil fuel dependency and greenhouse gas emission. Biofuel production from water hyacinth involves converting its lignocellulosic biomass into ethanol or biodiesel using various pretreatment and conversion methods. These methods include physical, chemical (acid/alkali), and biological (enzymatic) processes to break down the complex structure of the plant, release fermentable sugars, and facilitate the production of biofuels. Key steps include drying, grinding, pretreatment, hydrolysis to sugars, fermentation by microbes (like Saccharomyces cerevisiae), and distillation for ethanol, or lipid extraction for biodiesel.

## II. LITERATURE REVIEW:

There are different types of bio fuels are available .so, we choose water hyacinth as a bio fuel. We studied some of those papers and those papers them are mentioned as follows:

**S. M. M. Shanab.et al [1]:** This study evaluates seasonally harvested water hyacinth from the Nile as a lignocellulosic feedstock for both biodiesel and bioethanol, linking biochemical composition with fuel yield and quality. Reported lipid contents (≈6.8–10.5%) produced 3.2–6.4% biodiesel via transesterification; fatty acid profiles were season-dependent (myristic/stearic dominant; oleic detected only in summer), implying good oxidative stability for diesel substitution. Mild acid pretreatment enhanced fermentable sugars and ethanol over 120–180 minutes, underscoring the role of low lignin and high cellulose/hemicellulose in processability. Co-products (pigments, glycerol) add valorization pathways, and measured fuel properties met local diesel standards, positioning this invasive biomass as a waste-to-resource solution for Egypt.

**Ch. Vidya sagar.et al [2]:** This study Framed as a narrative overview, this paper advocates non-edible, abundant feedstocks for biodiesel to avoid food–fuel competition and highlights water hyacinth's ubiquity and low opportunity cost. It recaps base-catalyzed transesterification of triglycerides to FAMEs and emphasizes environmental/operational benefits (lubricity, higher flash point, lower toxic emissions) while situating hyacinth among diverse oil sources and animal fats. The contribution is primarily conceptual: arguing socio-economic co-benefits (waste control, rural income, pollution mitigation) and motivating small-scale deployments. However, it provides limited primary data on hyacinth lipid yields, extraction routes, or comparative fuel properties; references to standards (e.g., ASTM) are generic, and process variables (catalyst loading, FFA management) are not resolved.

**Gunjan.et al [3]:** The study A comprehensive review spanning water hyacinth, Azolla, salvinia, water lettuce, and duckweed, this paper synthesizes pathways (transesterification, pyrolysis, hydrolysis, torrefaction; AD and fermentation) and pretreatments (acid/alkali favored over hydrothermal for sugar release; ultrasound for lipid extraction). It compares physicochemical properties of resultant fuels against petroleum analogs and highlights that Azolla and water fern may yield higher-quality diesel-like fuels by calorific value/viscosity metrics, while noting research gaps for lettuce/duckweed. Crucially, it reframes invasive-plant removal costs as potential energy investments and provides a value-chain perspective (bio-oil/syngas to fuels; FAME via esterification; biogas/bio-$H_2$ alongside ethanol). The review's strengths are scope and operational guidance (e.g., lignin removal via NaOH) but it aggregates heterogeneous studies with varying baselines, so cross-study comparisons should be interpreted cautiously.

**R. Tao.et al [4]:** This dissertation positions water hyacinth bioconversion within global energy/climate imperatives and biofuel "generations," focusing on anaerobic routes enhanced by alkaline-waste pretreatments. It argues hyacinth's high holocellulose (≈44–66.9% dry matter) and low lignin enable effective biomethanation/fermentation, while alkaline streams facilitate lignin disruption and improve biodegradability. The thesis surveys pollution issues from fossil fuels, compares biofuel pathways (1st–4th gen), and justifies aquatic biomass on non-competition with cropland and high photosynthetic efficiency. Although details of reactor configurations, kinetics, and methane/ethanol yields are not in the excerpt, the work's novelty lies in coupling waste-alkali valorization with invasive-weed management, implying circularity and cost reduction. Future-facing themes include decentralized systems, continuous operation, and integration with wastewater treatment.

**A. Singh.et al [5]**: This experimental paper quantifies water hyacinth composition (cellulose+hemicellulose ≈58.6%; comparatively low lignin) and develops an effective alkali pretreatment enabling near-complete cellulase hydrolysis to reducing sugars. It systematically varies NaOH/$H_2SO_4$ loadings, liquid–solid ratios, temperature, and time, then analyzes structural changes (FTIR, SEM) to link delignification/hemicellulose disruption with saccharification efficiency. Achieving \~100% cellulose conversion in optimized conditions, it establishes WHB as a viable lignocellulosic sugar source for downstream ethanol. The rigor of pretreatment–hydrolysis coupling and clear metrics (FPU dosing, citrate buffer conditions, yield assumptions) strengthen its translational value. Limitations include focus on saccharification rather than full fermentation/ethanol titers, and lack of inhibitor profiling (furans/phenolics) or process economics. Still, it provides a robust unit-operation backbone for WH-to-bioethanol process design

**Y. Anke.et al [6]:** This recent article outlines a lab-scale route: Soxhlet extraction of hyacinth petiole lipids followed by base-catalyzed transesterification to FAME, positioning WH as a renewable, waste-derived diesel substitute. It reiterates standard biodiesel benefits and presents a schematic from extraction through methanol recovery and glycerine refining. As a teaching-style methods paper, it contributes a simple, accessible protocol suitable for academic labs or small workshops. However, critical quantitative details are sparse—oil yield from biomass, FFA content and pretreatment (e.g., esterification for high-FFA oils), catalyst levels, reaction kinetics, FAME profile, fuel properties (cetane, viscosity, CFPP), and engine performance are largely absent. Thus, its main value is procedural orientation and sustainability framing; future work should benchmark yields, conduct ASTM/EN compliance testing, and address logistics of harvesting, dewatering, and scaling lipid recovery from a low-oil aquatic plant

**R. Singh.et al [7]:** Targeting ethanol from waste biomass, this paper proposes a simplified, cost-effective scheme: mechanochemical activation as pretreatment, followed by fermentation and differential distillation—aiming to replace several conventional stages. It motivates aquatic plants (notably water hyacinth) due to non-competition for arable land, fast growth, and potential for water remediation; composition data (≈48% hemicellulose, 18% cellulose, \~3.5% lignin) underpin fermentability. The authors advocate localized, decentralized ethanol systems matched to dispersed biomass supplies to cut transport/infrastructure burdens and create rural economic benefits. While innovative in process intensification and system design, the article functions more as a conceptual/engineering proposal than a full pilot demonstration; quantitative yields, continuous-operation stability, and inhibitor/strain engineering specifics are limited in the excerpt. It points toward integrating remediation, pretreatment energy minimization, and continuous bioprocessing in practical deployments

**R. Suganeshwari.et al [8]:** This review centers on lignocellulosic conversion of WH to ethanol and other fuels, emphasizing pretreatment as the "make-or-break" step for cost and environmental profile. It classifies biofuels by generation, argues for WH's low-cost availability in India, and surveys acid/alkali/other pretreatments to open the hemicellulose-rich matrix while managing inhibitors. The piece synthesizes the broader energy context (transport's share of primary energy; biomass's distributed availability), positioning WH within national energy/waste strategies. Its strengths are clarity and accessibility; however, it provides limited comparative kinetics, inhibitor quantification, or techno-economic/lifecycle metrics. It is a useful primer for researchers entering WH conversion, with actionable takeaways: prioritize eco-friendly, efficient pretreatment; couple with local biomass logistics; and evaluate multi-fuel portfolios (bioethanol, biogas, hydrogen) to improve plant-wide utilization

**M. A. Arefin.et al [9]:** This paper an early position paper reframing a notorious invasive ornamental into a prospective biofuel crop, this article argues WH's low lignin and rapid propagation make it suitable for bioethanol and biogas production. It surveys ecological impacts (oxygen depletion, navigation and irrigation blockage) to justify valorization and suggests sustainable management via harvest-and-convert strategies. Being pre-demonstration in tone, it does not deliver detailed process performance but sets a research agenda that subsequent studies have pursued: compositional baselining, pretreatment optimization, and integrated waste-to-energy systems. Its contribution is thus catalytic—popularizing WH in the bioenergy discourse and highlighting market opportunities tied to environmental management—though modern readers should supplement it with contemporary empirical work for yields, costs, and policy frameworks

**A. Bhattacharya.et al [10]:** This paper proposes a dual-valorization concept: converting WH to ethanol via pretreatment–hydrolysis–fermentation–purification while channeling residual fibrous fractions into furniture/handicraft products. Technically, it favors acid/alkali pretreatments and details simple drying and NaOH soaking steps as accessible routes to open the plant matrix and increase sugar release. Conceptually, the co-product pathway addresses low fuel margins by adding materials revenue and local employment. The work is exploratory: it lacks mass/energy balances, product property testing, or durability metrics for furniture composites, and ethanol yield data are limited. Nonetheless, it anticipates the contemporary "biorefinery + circular economy" framing by coupling environmental remediation with diversified product streams, inviting follow-up on material engineering (binders, durability), fuel specs compliance, and village-scale enterprise models

**I. Bergie.et al [11]:** This article explores the Pantanal wetland's enormous biomass potential, especially water hyacinth, for biofuel production. It emphasizes concepts of ecosystem surplus and renewability, arguing that biomass can be harvested sustainably without harming ecological resilience. Using published hydrology and productivity data, the authors estimate biomass availability, energy balance, and carbon offsets. They highlight that aquatic biomass collection requires minimal fossil inputs, offering a positive energy return and low environmental disturbance. Water hyacinth's biochemical profile—rich in carbohydrates—supports ethanol and biogas potential, while its management aligns with carbon sequestration and rural development goals. The paper's strength lies in reframing invasive biomass as an ecosystem service, linking wetland management, climate mitigation, and socioeconomics. However, it lacks experimental conversion trials and relies on first-order estimations. It serves as a conceptual model for sustainable wetland bioeconomies, adaptable to other wetlands worldwide, though techno-economic and policy details remain undeveloped

**A. Kumari.et al [12]:** This study presents an integrated approach to derive both ethanol and biodiesel from water hyacinth using combined pretreatments. Biomass was dried, milled, and subjected to alkali and enzymatic hydrolysis with cellulase, releasing sugars for fermentation by Saccharomyces cerevisiae. Parallel Soxhlet lipid extraction yielded 8 g oil/100 g biomass, of which 90% converted to biodiesel. Ethanol production reached 8.1 mL/100 g, with glucose yields of 25 g/L. FTIR, UV-Vis, and HPLC confirmed fuel quality. Strengths include its holistic scope—bioethanol and biodiesel from the same feedstock—demonstrating dual valorization and potential circular economy benefits. However, yields are modest compared to terrestrial crops, and scale-up issues such as dewatering, inhibitor control, and process economics are not addressed. The paper effectively validates laboratory-scale feasibility of WH as a dual biofuel source and highlights its ecological value as an invasive species solution, yet practical deployment demands techno-economic analysis and optimization

**M. A. Bote.et al [13]:** This review synthesizes global research on water hyacinth as a biofuel resource, positioning it as both an ecological nuisance and an energy opportunity. It outlines biofuel pathways: ethanol, methanol, biodiesel, and biogas, with attention to pretreatment needs for lignocellulose saccharification. Citing studies on acid/alkali hydrolysis, it identifies sulfuric acid as particularly effective for sugar release. Beyond fuels, it notes ancillary uses like vermicomposting and pelletization for solid fuels. The review situates WH in India and globally, emphasizing its invasiveness, rapid biomass accumulation, and biodiversity impacts, which justify valorization. Its strengths lie in comprehensive coverage of conversion routes and ecological framing. However, it remains largely descriptive, with limited quantitative comparison of yields or energy balances, and does not deeply analyze process economics or scalability. It is most valuable as a literature survey motivating further applied studies in pretreatment optimization, integrated biorefineries, and decentralized energy model

**O. P. Ilo.et al [14]:** This original study investigates fungal pretreatment of water hyacinth for improved pyrolysis, applying Trichoderma atroviride—a novel approach. The pretreatment enhanced cellulose content (+25.4%) while reducing lignin (−23.4%), yielding higher pyrolysis oil (+25.8%) and less char. Optimization via response surface methodology identified temperature and particle size as key variables. The work advances the concept of biorefineries in a circular economy, showing biological delignification can enhance downstream thermochemical conversion without harsh chemicals. Strengths include detailed experimental design, integration of fungal bioprocessing with pyrolysis, and demonstration of improved yields. Limitations include scale: fungal pretreatment is time-intensive and may face challenges in industrial throughput. Moreover, oil stability and upgrading were not fully addressed. Nonetheless, this is an innovative step linking sustainable pretreatment with thermochemical valorization of invasive biomass, offering pathways for policy and industrial interest in resource recovery from aquatic weeds

**S. Sukarni,.et al [15]:** This characterization study analyzes WH biomass from Indonesian dams using proximate and elemental analyses (SEM-EDX, bomb calorimetry). Results: high oxygen (49.5%), moderate carbon (14.5%), volatile matter (61.2%), fixed carbon (13.8%), ash (20.1%), and a gross calorific value of 14.46 MJ/kg. These figures show WH has lower energy density than wood or coal but high volatiles, suggesting suitability for co-combustion. The study's strength lies in providing baseline data on WH's chemical and thermal properties, crucial for process modeling and technology choice (combustion, gasification, co-firing). However, its focus is narrow: no experimental conversion tests or comparisons to other aquatic biomass. Limitations include high ash content, which may cause fouling, and low calorific value, limiting standalone use. Nonetheless, the paper establishes WH as a supplemental, sustainable feedstock in mixed fuel systems and supports its use in hybrid energy strategies

**A. Das,.et al [16]:** This paper experimentally demonstrates dilute-acid pretreatment (2% $H_2SO_4$, high T/P) followed by enzymatic hydrolysis and mixed fermentation (S. cerevisiae + Z. mobilis). Optimized saccharification yielded 425.6 mg sugar/g biomass, while ethanol reached 13.6 mg/mL under central composite design. The study highlights key parameters—cellulase load (30 FPU), pH (5.5), temperature (50 °C)—for maximal efficiency. It frames WH as ideal due to low lignin, high cellulose, fast growth, and non-competition with croplands. Strengths include integration of pretreatment, saccharification, and fermentation, and statistical optimization. Limitations: ethanol yield per biomass unit is moderate, with no scale-up economics or inhibitor detoxification studies. Still, this is one of the more detailed lab-to-process studies, providing a strong basis for industrial WH ethanol production, particularly in tropical regions where the weed is abundant

**J. Onyango.et al [17]:** This study explores WH for solid biofuels, producing briquettes with binders (molasses, eucalyptus leaf powder, phytoplankton scum). Physical tests assessed density, durability, water resistance, and calorific value. Molasses-based briquettes achieved 1148 kJ/kg, eucalyptus-based 1090 kJ/kg, compared to 1423 kJ/kg for charcoal. WH briquettes showed adequate durability and resistance but lower energy density. The paper emphasizes WH's cellulose/hemicellulose content as suitable for solid fuel, while valorizing invasive biomass. Strengths: experimental validation of briquetting, binder comparison, and performance benchmarking. Weaknesses: calorific values remain low relative to coal/charcoal, limiting competitiveness; no emissions or long-term combustion studies. Nonetheless, it demonstrates a viable pathway for WH utilization in household/cottage industries, particularly in rural areas needing low-cost solid fuels, aligning waste management with local energy access

**D. R. Suminar.et al [18]:** This study investigates the use of coconut shells and water hyacinth to produce sulfonated carbon-based heterogeneous acid catalysts for biodiesel synthesis. The raw materials were carbonized at 300 °C and sulfonated with concentrated $H_2SO_4$ at 150 °C under varying times and cycles. Water hyacinth achieved a higher acid concentration (1.2 mmol/g) than coconut shell (1.215 mmol/g) after triple sulfonation. In esterification tests, the water hyacinth catalyst achieved better free fatty acid conversion (75.28%) compared to coconut shell (57.62%). Kinetic studies revealed faster reaction rates with water hyacinth (0.0139 L/mol·h) than coconut shell (0.0045 L/mol·h). FTIR confirmed S=O functional groups from $–SO_3H$, SEM showed amorphous surface morphologies, and XRD confirmed non-crystalline structures. Results indicate that both biomass wastes are suitable for catalyst synthesis, but water hyacinth demonstrates greater catalytic efficiency, making it a promising low-cost renewable option for biodiesel production.

**K. Nahar.et al [19]:** In This article investigates WH as a dual-purpose biomass: biofuel feedstock and phytoremediation agent. Lab experiments in Dhaka tested WH in eutrophic lakes, showing significant water-quality improvements (reduced turbidity, TDS, NaCl, EC; increased DO, pH). The harvested biomass was then proposed for bioethanol and biogas production. Framed as a "three-in-one nexus," WH supports energy generation, water purification, and eco-product development. Strengths include the novel coupling of ecosystem service (remediation) with energy recovery, and empirical data on pollutant removal. Weaknesses: biofuel conversion results are not deeply quantified, and economic feasibility is not discussed. Still, it contributes to sustainable resource-management literature, particularly in urbanizing regions where WH poses ecological and socio-economic challenges. It highlights the potential of turning environmental liability into a renewable energy asset.

**T. Paul.et al [20]:** This research explores bioethanol production from water hyacinth, an invasive aquatic weed with high cellulose and hemicellulose content. The biomass underwent dilute sulfuric acid pretreatment under high temperature and pressure to break down hemicellulose and expose cellulose. Enzymatic saccharification under optimized conditions (30 FPU cellulase, pH 5.5, 50 °C, 24 h) yielded 425.6 mg/g reducing sugars. Mixed fermentation using Saccharomyces cerevisiae and Zymomonas mobilis optimized through central composite design produced 13.6 mg/ml ethanol. SEM analysis confirmed structural disruption of pretreated biomass, while compositional analysis revealed reduced hemicellulose and increased accessible cellulose. The study highlights water hyacinth as a cost-effective, non-food bioethanol feedstock that avoids competition with arable land, while also addressing environmental issues such as waterway blockage and biodiversity loss. The results support water hyacinth's dual role in bioenergy generation and ecological management.

**S. Tadesse.et al [21]:** This study examined the potential of converting water hyacinth from Lake Koka, Ethiopia, into biodiesel. The study measured key fuel parameters such as specific gravity (0.912 g/ml), acid value (0.4 mgKOH/g), viscosity (2.7 $mm^2$/sec), and ash content (0.001%), which all conformed to American and European biodiesel standards. Nutritional analysis revealed high moisture (76.2%), modest protein (10.23%), and extremely low lipid content (0.49%), posing challenges for economic scalability. While the research confirmed the technical viability of water hyacinth biodiesel, it also highlighted that its oil yield was too low to sustain cost-effective large-scale production. Nonetheless, the plant's widespread availability in Ethiopian lakes makes it a potential renewable feedstock, especially when integrated with waste management and ecological restoration strategies. The findings underline water hyacinth's promise as a renewable energy resource but stress the importance of technological innovations to overcome low oil content limitations.

**S. Mekonnen.et al [22]:** The investigated water hyacinth's suitability as a biofuel feedstock compared to traditional vegetable oils such as jatropha, sunflower, and palm. Unlike food-based crops, water hyacinth offers no major competing uses, making it an ideal candidate for bioethanol and biodiesel production. Classified as one of the world's top invasive weeds, it poses ecological and economic burdens, with annual damages in Africa estimated at \$20–100 million. The study emphasized its lignocellulosic composition, which allows efficient bioethanol conversion without requiring arable land. Ethanol derived from water hyacinth showed potential as a transport fuel due to its miscibility with gasoline and high octane number, although technical barriers such as cold-start problems remain. Flexible fuel vehicles using E85 blends (85% ethanol, 15% gasoline) were highlighted as solutions. Overall, the paper presented water hyacinth as a promising, eco-friendly, and renewable alternative to fossil fuels, with strong potential for small-scale energy generation.

**M. M. Rahman.et al [23]:** This review explored biodiesel production from water hyacinth using in situ transesterification with methanol and ethanol, while comparing samples collected from two Brazilian regions. Gas chromatography revealed that the collection site significantly influenced biodiesel yield and quality, with environmental conditions such as ammonia concentration affecting biomass composition. Ethanol-based transesterification achieved higher yields than methanol, aligning with Brazil's abundant sugarcane ethanol supply. The biodiesel's fatty acid composition and physicochemical properties, simulated through were comparable to commercial biodiesel (BD100), indicating commercial viability. Furthermore, the study underscored water hyacinth's dual role as a biofuel source and an environmental solution by simultaneously producing clean energy and reducing aquatic pollution. Despite low intrinsic lipid content, process optimization and site-specific management were found to improve yields. This research provides important insights into how environmental variables and choice of alcohol affect the scalability of biodiesel production from invasive aquatic plants.

**B. Y. Hirphaye.et al [24]:** This investigated a multi-fuel approach by converting water hyacinth from Lake Abaya into biogas, biodiesel, and briquettes. Physicochemical analysis showed high moisture content (89%) and a favorable carbon-to-nitrogen ratio (1:20.25) for biogas generation. Anaerobic digestion with cow dung produced up to 38.46 L of biogas, while transesterification confirmed its potential for biodiesel production. Biomass briquettes were successfully created by carbonizing hyacinth and mixing with binders, offering an affordable solid fuel alternative. Cellulose (34.69%) and hemicellulose (38.8%) content reinforced its value as a lignocellulosic feedstock. Beyond energy generation, this strategy aimed to reduce the ecological damage caused by water hyacinth infestations that threaten fisheries, irrigation, and biodiversity. The study emphasized eco-sanitation benefits, presenting energy recovery as a win-win solution that combines invasive species control, renewable fuel production, and livelihood support for local communities dependent on lake resources.

**T. P. Rao.et al [25]:** This focused on optimizing drying temperatures of water hyacinth biomass to improve biodiesel yield and quality. Biomass collected from Andhra Pradesh was subjected to drying at 120°C, 130°C, and 140°C, followed by lipid extraction and transesterification. Results indicated that higher drying temperatures improved both yield and fuel quality. At 140°C, biodiesel yield reached 416.4 ml, compared to 399.7 ml at 120°C. Importantly, fuel properties such as density, viscosity, flash point, and cetane number were significantly enhanced at higher temperatures, while acid value and water content decreased. The study demonstrated that pre-treatment through optimized drying is critical for overcoming water hyacinth's high moisture content, which often limits lipid extraction efficiency. By establishing a straightforward and low-cost optimization method, this research reinforced the viability of water hyacinth as a renewable feedstock and highlighted the importance of process improvements in scaling biodiesel production from invasive biomass.

**A. K. Shendge.et al [26]:** His review conducted a case study in Solapur City, India, on the production of biofuels from aquatic waterweeds, with emphasis on water hyacinth. The study highlighted sustainability as a guiding principle, emphasizing economic, social, and environmental benefits of small-scale biofuel production. Water hyacinth biomass was shown to contain variable sugar (1–1.2%) and alcohol (2–2.4%) yields from acid hydrolysis and fermentation of 1.5 kg samples. While modest, these results demonstrated the feasibility of producing bioethanol as an alternative to fossil fuels. The authors also emphasized the environmental advantages, such as reduced particulate emissions and lower carbon output compared to petro-diesel. Additionally, the study positioned biofuels as lubricants that extend engine life, making them attractive substitutes for petroleum-based fuels. Importantly, this research presented biofuel production as a waste management strategy for invasive aquatic weeds, turning ecological burdens into renewable energy opportunities.

**P. Yadav.et al [27]:** This study compared direct (co-pyrolysis) and indirect (co-gasification with Fischer–Tropsch synthesis) thermochemical methods for producing liquid fuels from water hyacinths and waste tires. Using Aspen Plus simulations, the study optimized process conditions to maximize fuel yield and assessed economic viability. Results showed that co-pyrolysis at 400°C with a 75:25 tire-to-hyacinth ratio yielded 6,649 gal/day of liquid fuel, while co-gasification at 800°C with a 50:50 ratio produced syngas that, when processed via Fischer–Tropsch, generated 8,817 gal/day. The indirect method provided higher yields and better economic outcomes, although it was more complex. Importantly, co-processing addressed water hyacinth's limitations (high moisture and low calorific value) while reducing tire waste. The study underscored the synergy of combining problematic waste streams to create sustainable fuels, highlighting both environmental and economic benefits of integrating biomass and industrial waste into circular energy systems.

**S. Mishra.et al [28]:** This work provided a comprehensive review of the chemical composition, pharmacological potential, and renewable energy applications of Eichhornia crassipes. The review summarized the plant's secondary metabolites, including alkaloids, terpenoids, flavonoids, tannins, and saponins, which underpin its pharmacological activities such as antioxidant, antifungal, anticancer, and antibacterial effects. From an energy perspective, its high lignocellulosic content, nutrient-rich biomass, and absence of heavy metals in tested samples make it a promising substrate for bioethanol, biodiesel, and compost production. However, the review also highlighted its destructive ecological impact, such as clogging waterways, reducing biodiversity, and supporting mosquito-borne diseases. The authors emphasized turning this invasive weed into an economic resource through value-added applications, including biofuel, phytoremediation, and bioproducts. This dual perspective positioned water hyacinth both as an environmental challenge and as an underutilized biomass with multipurpose industrial and medicinal value, calling for integrated management strategies.

**T. Mahmood.et al [29]:** This study developed novel nanocatalyst-based methods for producing biofuels from metal-accumulating water hyacinth. Three approaches were tested: acid saccharification and fermentation for bioethanol, catalytic gasification using nickel and cobalt nanoparticles, and photocatalytic conversion with titanium dioxide. Acid hydrolysis produced 55.2% ethanol and 41.6% acetic acid, while catalytic gasification yielded hydrocarbons such as methane, ethylene, and methanol. Photocatalysis at room temperature also generated methane and ethanol, demonstrating low-energy conversion potential. This study was unique in using metal-contaminated water hyacinth, highlighting its dual role in biofuel generation and environmental remediation of polluted waters. The results demonstrated that advanced catalytic and photocatalytic processes can transform an invasive and hazardous biomass into multiple valuable fuels. While scalability challenges remain, this work showcased the potential of integrating nanotechnology with biomass conversion for sustainable, efficient, and eco-friendly energy production.

**N. Photong.et al [30]:** This study Photong and Wongthanate compare biomethane via anaerobic digestion of water hyacinth (WH) blended with cassava starch sediment (CS) against densified bio-briquettes from the same feedstocks. Optimized AD (WH\:CS 25:75, pH 7.5, 55 °C, C/N ≈ 30) achieved a peak yield of \~437 mL $CH_4$ $gCOD^{-1}$ with \~87% COD removal; in electricity terms, the biological route (\~3.9 kWh) outperformed briquettes (1.42–1.52 kWh for WH\:CS 50:50→10:90). Fuel property tests showed WH–CS briquettes (10–50% WH) met Thai community standards with heating values \~14.6–15.7 MJ $kg^{-1}$, while prior literature cited WH's rapid growth, nitrogen richness, and potential to offset synthetic nutrients in digestion. The study strengthens the case for WH valorization and co-processing of agro-industrial residues, highlighting tangible operating windows (temperature, pH, blending ratio) and energy trade-offs between biochemical and thermochemical densification pathways for decentralized waste-to-energy systems.

**B. M. Jyothi.et al [31]:** This study explores biodiesel production using water hyacinth (Eichhornia crassipes), an invasive aquatic plant with high biomass potential. Collected from Rachenahalli Lake in Bengaluru, India, the plant was processed as raw feedstock under optimal conditions. Biodiesel synthesis was performed through transesterification, employing methanol as the alcohol and potassium hydroxide (KOH) as the catalyst. The reaction yielded biodiesel and glycerol, which were separated using a separatory funnel. The produced biodiesel underwent laboratory testing for key fuel properties such as density, viscosity, flash point, and calorific value. These values were then compared with established biodiesel standards to assess quality and applicability. Results indicated that water hyacinth biodiesel possesses properties within acceptable ranges, demonstrating its potential as an alternative renewable fuel. By utilizing an abundant aquatic weed, this approach not only offers a sustainable biofuel source but also contributes to controlling environmental issues associated with uncontrolled water hyacinth growth.

**S. A. Kumar.et al [32]:** water hyacinth's (Eichhornia crassipes) biology and valorization pathways, reframing a prolific aquatic weed as a renewable resource. Beyond established roles as sorbents for metals and dyes, the authors survey advances in extracting bio-actives (sterols, phenolics) and generating nanocellulose, biochars, and composites. They synthesize kinetics and isotherms for heavy-metal uptake, show extraction process optimization (e.g., supercritical $CO_2$ favoring stigmasterol), and discuss emerging applications—including energy (biogas/ethanol), supercapacitors, and reinforcement fibers. Critically, they quantify growth potential (doubling in days; multi-ton per-hectare yields), underscoring vast, low-cost biomass supply that simultaneously mitigates ecological harms when harvested. The review's contribution is breadth: it links structure–property insights (cellulose/hemicellulose/lignin fractions, fiber dimensions) with processing routes and product performance, laying out a technoopportunity map for circular utilization across chemicals, materials, and energy while acknowledging control costs and the need for scalable, economical deweeding-to-product chains

**N. Wichianphong.et al [33]:** This study developed Wichianphong and Maison pelletize mixtures of dried water hyacinth (WH) and spent coffee grounds (SCG) using cassava-starch binders (5–20% w/w) to enhance fuel quality. Systematic blending (WH\:SCG = 100:0→60:40) shows calorific value rises with SCG content; the 60:40 blend peaks at \~17.19 MJ $kg^{-1}$ while meeting acceptable moisture and volatile standards for wood pellets. Binder concentration has no significant effect on key fuel properties across 5–20% range, suggesting formulation flexibility and cost savings. The study situates WH as abundant but low-HHV biomass whose deficits can be engineered away via co-pelletization with high-energy residues like SCG, aligning with prior reports advocating co-feeding to improve combustibles and densification performance. By reporting a realistic small-diameter (6 mm) pellet form factor and standard proximate metrics (moisture, ash, volatile matter, fixed carbon), the work offers a practical recipe for community-scale solid biofuel production that also alleviates aquatic-weed and urban organic-waste burdens.

**F. E. Soetaredjo.et al [34]:** This research proves that design a two-step route that converts WH cellulose/hemicellulose into levulinic acid (LA) using subcritical water with acid-activated zeolite, followed by catalytic hydrogenation ($Pt/TiO_2$ + acid zeolite) to γ-valerolactone (GVL), a versatile biofuel intermediate. Alkali pretreatment removes lignin, then optimized hydrolysis at 200 °C, 40 bar, 120 min yields \~173 mg LA per g dry WH. Subsequent hydrogenation achieves >95% LA conversion to GVL across 160–220 °C, evidencing strong synergy between metal and Bronsted sites. Framing WH within "second-generation" lignocellulosics, the authors argue this non-food, invasive feedstock circumvents food–fuel conflicts while leveraging abundant Asian biomass. The paper advances integrated catalytic valorization of problematic aquatic weeds, quantifying conditions and yields that make GVL production plausible as part of distributed biorefineries, provided challenges around pretreatment, catalyst stability, and aqueous-phase separations are addressed for scale-up.

**D. R. Suminar.et al [35]:** This study proved that This study investigates the development of heterogeneous acid catalysts from coconut shells and water hyacinth for biodiesel production. The biomass was carbonized at 300 °C and sulfonated using concentrated sulfuric acid at 150 °C with varying times and cycles. The acid density of the catalysts increased with longer sulfonation times and multiple cycles, with water hyacinth achieving 1.2 mmol/g and coconut shell 1.215 mmol/g after triple sulfonation. Esterification tests revealed that the water hyacinth catalyst had higher efficiency, converting 75.28% of free fatty acids (FFA) compared to 57.62% for coconut shell. Kinetic analysis showed faster reaction rates for water hyacinth (0.0139 L/mol·h) than coconut shell (0.0045 L/mol·h). FTIR confirmed the presence of $–SO_3H$ groups, while SEM and XRD analyses indicated amorphous carbon structures with irregular morphologies. The results demonstrate that both waste materials can serve as effective, low-cost sulfonated carbon catalysts, with water hyacinth showing superior catalytic performance.

**S. Awasthi.et al [36]:** This study presents a conference-level overview of producing biofuels—especially ethanol—from WH, contextualizing India's energy security and the appeal of low-cost lignocellulosic feedstocks. Summarizing prior optimization with Zymomonas mobilis (e.g., substrate 200 g $L^{-1}$, pH 4.5, \~3.25 days, enzyme 50 g $L^{-1}$ producing \~68 g $L^{-1}$ ethanol), they argue WH's cellulose/hemicellulose content, rapid growth, and ubiquity in Rajasthan lakes make it a compelling candidate. The paper is primarily a narrative review with regional situating; it touches on biodiesel and broader biomass-to-energy rationales, and notes post-extraction residue valorization (e.g., papermaking). While experimental novelty is limited, the contribution lies in aggregating literature to advocate localized WH-to-bioethanol initiatives and highlighting socioeconomic benefits (waste remediation, rural energy) alongside standard biofuel advantages (biodegradability, lower net carbon). Future work should deepen techno-economic analysis, pretreatment selection, and fermenter design specific to Indian WH logistics and seasonal variability.

**N. Merry.et al [37]:** This review balances WH's ecological impacts—oxygen depletion, impeded navigation, biodiversity stress—with its valorization potential in energy and wastewater treatment. The paper synthesizes reports on ethanol, biogas, briquetting, and incineration, emphasizing biological pretreatments and co-digestion strategies to accelerate hydrolysis and methane yields (e.g., microbial consortia; earthworm-enhanced systems at mesophilic temperatures with optimized TS, pH, and particle size). It also underscores WH's role in BOD removal and as an adsorbent, leveraging root–surface biofilms. The contribution is an accessible, holistic lens linking fundamentals (growth in warm waters; seed bank dynamics) with applied pathways that turn a pervasive nuisance into resource streams. Although data depth is modest, the integration of operational variables (TS, pH, particle size), treatment mechanisms, and dual environmental–energy benefits makes it a useful primer for practitioners exploring low-cost WH management coupled with renewable-energy generation.

**Abba.et al [38]:** The study conducts a PRISMA-guided review (2005–2025) of WH-based energy systems, arguing that integrated, multi-product biorefineries can shift WH from invasive burden to circular-bioeconomy asset. Synthesizing 174 studies, they report indicative gains—LCOE reductions (\~25%), ethanol yield increases (\~40%), and sugar-release improvements (\~50%)—and estimate biorefinery co-products (biochar/fertilizers) could offset up to \~2.5 t $CO_2$ $ha^{-1}$ $yr^{-1}$. They highlight policy/market gaps (pilot-scale paucity, governance misalignment) and propose four frameworks—CBIF, SETF, PIF, and CBIF-2—connecting technology, regulation, and community adoption. Case vignettes from India, Nigeria, Bangladesh, and Kenya illustrate livelihood linkages (biogas, crafts, paper) and the need for participatory models. The review's value is its systems perspective: it triangulates techno-economic, environmental, and social dimensions to chart credible deployment pathways while calling for standardized TEA/LCA, feedstock logistics, and risk-aware ecological safeguard.

**A. Ajithram.et al [39]:** This review showed that fabricate sulfonated-carbon solid acids from WH and coconut shells (carbonized 300 °C, sulfonated with $H_2SO_4$ at 150 °C) and benchmark them for esterification relevant to biodiesel pretreatment. Both materials achieve similar acid site densities (\~1.2 mmol $g^{-1}$), but WH-derived catalysts show higher catalytic activity: \~75% ester conversion and a larger apparent rate constant (0.0139 L $mol^{-1}$ $h^{-1}$) versus coconut shell (\~58%, 0.0045). FTIR confirms $–SO_3H$ incorporation (S=O bands near 1034 $cm^{-1}$); SEM/XRD indicate amorphous carbons. The study demonstrates up-cycling WH into effective, separable solid acids that address high-FFA feeds and avoid drawbacks of homogeneous acids (separation, corrosion). While durability cycling and deactivation pathways merit further study, the results position WH as both feedstock and catalyst precursor in integrated biodiesel schemes, expanding the circularity and economics of aquatic-weed biorefineries

**G. Adwek.et al [40]:** This study explore social–technical feasibility for WH bioenergy around Lake Victoria through interviews with local stakeholders. Communities recognize WH's harms (water quality deterioration, fisheries disruption, irrigation blockage) yet already use it for livelihoods (organic fertilizer, crafts), implying potential competition with energy uses. The paper argues that scaling bioenergy requires participatory planning that respects existing value chains and affordability constraints, aligning bioenergy options (e.g., biogas, briquettes) with local priorities. As a case study, it contributes contextual insight often missing from technology-centric analyses, foregrounding adoption barriers and co-benefits in an East African setting. The findings support a nuanced strategy: leverage the abundant regional biomass for renewable energy while co-designing interventions that safeguard current incomes, thus improving acceptance and sustainability of WH removal and conversion program

# IV. METHODOLOGY

Transesterification is a chemical process where vegetable oils or animal fats (triglycerides) react with alcohol (usually methanol or ethanol) in the presence of a catalyst 6 to form biodiesel (fattyacid methylesters , or FAME)and glycerolas a by product

Steps in Transesterification (Adapted for Water Hyacinth):

1.Collection and Drying Fresh water hyacinth First, it must be harvested, washed, and thoroughly dried

2.Oil Extraction Water hyacinth has a low lipid content Solvent extraction is Used to extract whatever trace of oil are present.

3.Transesterification Reaction Mix the extracted oil with methanol and NaOH.

**V.CONCLUSION:** Water hyacinth is a promising, sustainable resource for biofuels like bioethanol and biodiesel, offering a solution to the plant's invasive growth that damages ecosystems. Significant progress has been made in converting this abundant biomass into fuel, with pretreatment methods essential to breaking down its tough structure and increasing sugar and oil yields. Integrating water hyacinth processing into biorefineries can improve economic viability by producing multiple products and reducing environmental impacts, though large-scale implementation requires further advances in efficient, cost-effective technology. Water hyacinth feedstock for biofuel production. Key conclusions include its high cellulose content and low lignin, making it suitable for production of biofuel. Water hyacinth can be a good source for biofuel production because it grows quickly and abundantly, doesn't need farmland, and has a high cellulose content that can be converted into usable fuel. This could help with both energy production and managing the environmental problems caused by this invasive plant.

## REFERENCES :


1. S. M. M. Shanab, E. A. Hanafy, and E. A. Shalaby, 'biodiesel production and antioxidant activity of different egyptian date palm seed cultivars,' asian J. Biochem., Vol. 9, no. 3, pp. 119 130, 2014.
2. Ch. Vidya sagar and N. Aruna kumari, 'sustainable biofuel production from water hyacinth (eicchornia crassipes),' international journal of engineering trends and technology (IJETT), vol. 4, no. 10, pp. 4454-4458, oct. 2013.
3. Gunjan, 'anaerobic conversion of water hyacinth to biofuel using alkaline waste,' ph.D. Dissertation, dept. Of chemistry, faculty of science, dayalbagh educational institute (deemed to be university), dayalbagh, Agra, India, 2022.
4. R. Tao, R. Zeng, X.-Y. Yin, S.-X. Zhang, and Z.-H. Yang, "Water hyacinth biomass as a biofuel feedstock by enzymatic hydrolysis," Bio Resources, vol. 11, no. 1, pp. 2372–2380, Jan. 2016, doi: 10.15376/biores.11.1.2372-2380.
5. A. Singh, V. Yadav, V. P. Sharma, B. P. Yadav, and M. Singh, "Production of biodiesel from water hyacinth by using extraction process and transesterification," Int. J. Sci. Res. Dev. (IJSRD), vol. 12, no. 3, pp. 251–256, 2024.
6. Y. Anker, F. Nakonechny, B. Niazov, S. Lugovskoy, and M. Nisnevitch, "Biofuel production by fermentation of water plants and agricultural lignocellulosic by-products," in Proc. ICMIT 2016, MATEC Web Conf., vol. 120, p. 05007, 2016.
7. Gunjan and R. Singh, "extraction of biofuels from water hyacinth: A review," environ. Toxicol. Stud. J., Vol. 5, no. 4, pp. 1–7, sep. 2021.
8. R. Suganeshwari and K. Ramani, "production of bio-fuel and furniture products using water hyacinth," SSRG int. J. Chem. Eng. Res. (SSRG–IJCER), vol. 1, no. 1, pp. 13–15, sep.–Dec. 2014. 131
9. M. A. Arefin, F. Rashid, and A. Islam, 'A review of biofuel production from floating aquatic plants: an emerging source of bio-renewable energy,' biofuels, bioprod. Bioref., Vol.15, no. 3, pp. 574–591, 2021.
10. A. Bhattacharya and P. Kumar, "water hyacinth as a potential biofuel crop," electronic journal of environmental, agricultural and food chemistry, vol. 9, no. 1, pp. 112–122, jan. 2010.
11. I. Bergier, S. M. Salis, C. H. B. Miranda, E. Ortega, and C. A. Luengo, "biofuel production from water hyacinth in the pantanal wetland," ecohydrology & hydrobiology, vol. 12, no. 1, pp. 77–84, 2012.
12. A. Kumari and S. Dubey, 'production of bioethanol and biodiesel from water hyacinth,' journal of neonatal surgery, vol. 14, no. 28s, pp. 56-73, 2025.
13. M. A. Bote, V. R. Naik, and K. B. Jagadeeshgouda, "review on water hyacinth weed as a potential bio fuel crop to meet collective energy needs," materials science for energy technologies, vol. 3, pp. 397–406, 2020.
14. O. P. Ilo and M. D. Simatele, "water hyacinth biorefinery: improved biofuel production using trichoderma atroviride pretreatment," biofuels, bioprod. Bioref., Vol. 19, pp. 68–84, 2025.
15. S. Sukarni, Y. Zakaria, S. Sumarli, R. Wulandari, A. A. Permanasari, and M. Suhermanto, "physical and chemical

properties of water hyacinth as a sustainable biofuel feedstock," IOP conf. Ser.: Mater. Sci. Eng., Vol. 515, no. 1, p. 012070, 2019.

16. A. Das, P. Ghosh, T. Paul, U. Ghosh, B. R. Pati, and K. C. Mondal, "production of bioethanol as useful biofuel through the bioconversion of water hyacinth (eichhornia crassipes)," 3 biotech, vol. 6, no. 70, 2016.
17. J. Onyango, K. Babu, S. Njuguna, W. Wanzala, and X. Yan, "harnessing the potential of common water hyacinth as an industrial raw material for the production of quality biofuel briquettes," SN appl. Sci., Vol. 2, p. 1316, 2020. 132.
18. D. R. Suminar et al., "Comparison of carbon-based heterogeneous acid catalyst from water hyacinth and coconut shell for biofuel production," trends sci., Vol. 21, no. 6, p. 7601, 2024.
19. K. Nahar and S. A. Sunny, "co-benefits of water hyacinth as sustainable biomass for biofuel production and aquatic ecosystem phytoremediation", fuels, vol. 5, no. 3, pp. 317– 333, 2024.
20. A. Das, P. Ghosh, T. Paul, U. Ghosh, B. R. Pati and K. C. Mondal, "production of bioethanol as useful biofuel through the bioconversion of water hyacinth", 3 biotech, vol. 6, no. 70, pp. 1–9, feb 2016.
21. S. Tadesse, H. Berhie, B. Kifle, and G. Tesfaye, "Production and characterization of bio- diesel from water hyacinth (Eichhornia crassipes) of Lake Koka, Ethiopia," American Journal of Applied Chemistry, vol. 10, no. 3, pp. 62–66, May 2022.
22. S. Mekonnen and M. G. Gabbiye, "Production of bioethanol from water hyacinth (Eichhornia crassipes) by acid hydrolysis fermentation process," International Journal of Innovative Science and Research Technology, vol. 5, no. 12, pp. 396–402, Dec. 2020.
23. M. M. Rahman, A. I. M. Al-Bari, and M. A. Rahman, "Biofuel from water hyacinth: A renewable energy source in Bangladesh," Energy and Power Engineering, vol. 7, no. 2, pp. 59–70, Apr. 2015.
24. B. Y. Hirphaye, F. H. Mezgebe, A. M. Tura, and G. M. Fanta, "Biogas, biodiesel and briquettes production from water hyacinth (Eichhornia crassipes) to reduce its impact on Lake Abaya as a win-win eco-sanitation strategy," SSRN Electronic Journal, preprint, Jun. 2023.
25. T. P. Rao, M. Adusuri, and J. V. Donipati, "Optimization of drying temperatures for enhanced biodiesel production from water hyacinth (Eichhornia crassipes)," International Journal of Advanced Biochemistry Research, vol. 8, no. 11, pp. 996–1003, Nov. 2022.
26. A. K. Shendge and B. Balapgol, "Generation of Bio-fuel by Using Waterweeds: A Case Study in Solapur City," Journal of Petroleum & Environmental Biotechnology, vol. 9, n3, p. 375, Jul. 2018.
27. P. Yadav, S. S. Baghel, S. Singh, and R. K. Singh, "Water Hyacinth as a Source of no. 6, pp. 174–178, Jun. 2019.Biofuel," Journal of Emerging Technologies and Innovative Research, vol. 6.
28. S. Mishra and S. S. Bandyopadhyay, "Biofuel Production from Water Hyacinth through Fermentation and Catalytic Processes," International Journal of Renewable Energy Research, vol. 11, no. 2, pp. 553–560, 2021.
29. T. Mahmood, S. T. Hussain, and S. A. Malik, "New nanomaterial and process for the production of biofuel from metal hyper accumulator water hyacinth," African Journal of Biotechnology, vol. 9, no. 16, pp. 2381–2391, Apr. 2010.
30. N. Photong and J. Wongthanate, "Biofuel production from bio-waste by biological and physical conversion processes," Waste Management & Research, vol. 37, no. 1, pp. 50–59, Jan. 2019.
31. B. M. Jyothi, C. J. Ramanan, A. Jain, A. Buradi, B. J. Bora, P. Sharma, and R. Kumar, "Biofuel Production from Water Hyacinth for Energy and Environment Sustainability," in Advances in Fluid and Thermal Engineering, B. S. Sikarwar, et al., Eds. Singapore: Springer, 2023, pp. 543–553.
32. S. A. Kumar, B. S. Harshitha, and R. Jayaprabakar, "Sustainable Bioethanol Production from Water Hyacinth (Eichhornia crassipes) – A Review," Mater. Today: Proc., vol. 72, pp. 2664–2669, 2023.
33. N. Wichianphong and W. Maison, "Preparation of biofuel pellets from water hyacinth and waste coffee grounds," RMUTSB Acad. J., vol. 8, no. 2, pp. 140–152, 2020.
34. F. E. Soetaredjo, Y.-H. Ju, and S. Ismadji, "Conversion of water hyacinth Eichhornia crassipes into biofuel intermediate: combination subcritical water and zeolite based catalyst processes," Can Tho Univ. J. Sci., Special Issue: Renewable Energy, pp. 64–69, 2016.

35. D. R. Suminar, I. Rahayu, E. Andrijanto, F. Y. M. Anam, F. Fadhillah, F. S. Irwansyah, and D. R. Eddy, “Comparison of Carbon-Based Heterogeneous Acid Catalyst from Water Hyacinth and Coconut Shell for Biofuel Production,” Trends Sci., vol. 21, no. 6, p. 7601, 2024. 134.

36. S. Awasthi, S. Lal, M. Kumar, A. Kumar, A. Mishra, and D. Kumhar, “The Extraction of Biofuel by Eicchornia Crassipes (Water Hyacinth),” in Proc. Nat. Conf. on Scientific World Around You and in Cosmos (NCSWAYC-2020), Banswara, India, 2020.

37. N. Merry, M. Mitan, “Water hyacinth: Potential and Threat,” Materials Today: Proceedings, vol. 19, pp. 1408–1412, 2019.

38. Abba, S. Sabarinath, and R. A. Mustapha, “Advancing circular bioeconomy through systematic review of multi-product biorefinery approaches for water hyacinth based renewable energy,” iScience, vol. 28, pp.1-17, Jul. 2025.

39. A. Ajithram, J. T. Winowlin Jappes, and N. C. Brintha, “Investigation on utilization of water hyacinth aquatic plants towards various bio products – Survey,” Materials Today: Proceedings, vol. 45, pp. 2040–2045, 2021.

40. G. Adwek, G. Julius, B. Shen, M. Lan, K. M. Cecilia, and A. C. Yabo, “Water hyacinth as a possible bioenergy resource: A case of Lake Victoria, Kenya,” IOP Conference Series: Earth Environmental Science, vol. 227, pp. 022-007, 2019.