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Techno-Economic Assessment and Plant Design for Biodiesel Production from Rice Bran Oil in the Philippines via Acid- and Base-Catalyzed Processes

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Biodiesel, is produced from biomass-based oils like vegetable or animal fats. Among second-generation oil sources, rice bran oil stands out as a viable feedstock due to its benefits, including increased food production, wealth creation through rice farming, and the economic value of utilizing rice waste. The Acid-Esterification Base-Transesterification (AEBT) process is used to convert rice bran oil into biodiesel, with esterification reducing Free Fatty Acids (FFA) to prevent saponification and enhance yield and quality. The production process is then simulated using Aspen HYSYS, with feasibility assessed based on economic viability, market potential, process complexity, and product usefulness. Given the rising demand for biodiesel due to environmental concerns, finite fossil fuel reserves, and fluctuating petroleum prices, establishing a biodiesel plant in the country offers significant economic and environmental benefits. The feasibility study indicates a return on investment of 62.16 %, with a 1.61-y payback period. The plant is designed to produce approximately 57,742 t of biodiesel annually across three production sections. This study aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) by promoting renewable energy and SDG 9 (Industry, Innovation, and Infrastructure) by fostering sustainable industrial development. By leveraging rice bran oil for biodiesel production, this research supports sustainable energy development and economic resilience in the Philippines.

1. Introduction

Growing concerns about climate change, the depletion of fossil fuels, and environmental deterioration have put the global energy sector at a pivotal juncture. The transportation sector is actively looking for cleaner, renewable fuel sources because it contributes significantly to global greenhouse gas emissions. One of the most promising options for meeting this need is biodiesel, which is described by Basu (2010) as a fuel made of mono-alkyl esters of long-chain fatty acids obtained from vegetable or animal fats. Its non-toxic, biodegradable nature and compatibility with existing diesel engines make it a viable substitute for petroleum-based diesel (Benjumea, 2008). Biodiesel does not contain petroleum, though it can be blended with it, and offers a clean-burning profile with negligible sulfur and aromatic content.
Historically, the viability of biodiesel was demonstrated by Rudolf Diesel in 1898, whose compression ignition engine ran successfully on peanut oil, marking a significant milestone in alternative fuel development (Roberts et al., 2014). Since then, numerous feedstocks—ranging from animal fats to waste cooking oils—have been utilized, with increasing attention now directed toward second-generation biofuels derived from non-food biomass. One such promising feedstock is rice bran oil, which is abundant in many Asian countries. This oil, extracted from the outer layer of rice grains, contains a high proportion of lipids and bioactive compounds, making it a cost-effective and valuable input for biodiesel production (Ju and Vali, 2005). The process also adds value to agricultural waste, creating economic opportunities for rural communities and aligning with circular economy principles.

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As mandated by Republic Act No. 9367 or the Biofuels Act of 2006 (Republic of the Philippines, 2007), which requires the incorporation of biofuels into the nation's fuel availability, is a single element of legislation that demonstrates the Philippines' goals of energy security. There is an urgent need to diversify feedstock sources due to the rising demand for biodiesel and the current over-reliance on coconut oil by current manufactures. Utilizing rice bran oil provides a strategic advantage by supporting the nation's sustainable development goals, encouraging local agriculture, and making use of already-existing agricultural byproducts. Building a new biodiesel plant with this substitute feedstock might boost economic growth, lessen its impact on the environment, and greatly increase the supply of energy in the country.

This study proposes the design and simulation of a biodiesel production plant in the Philippines using acid-esterification and base-transesterification (AEBT) processes, with Aspen HYSYS v9.0 as the simulation platform. The research evaluates the technical and economic feasibility of producing biodiesel from rice bran oil and provides a comprehensive market assessment to determine profitability and sustainability. Furthermore, location selection for the plant utilizes the PROMETHEE method to ensure optimal resource and logistics planning.

Aligned with the United Nations Sustainable Development Goals (UN SDGs)—specifically Goal 7: Affordable and Clean Energy, Goal 9: Industry, Innovation, and Infrastructure, Goal 12: Responsible Consumption and Production, and Goal 13: Climate Action—this study contributes toward a more resilient and low-carbon energy system.

2. Market Study

A visual overview of the key trends discussed in this section is presented in Figure 1. The infographic highlights global biodiesel market growth projections, the distribution of biodiesel usage by sector, comparative biofuel production volumes from leading producer countries in 2020 (in t), and the Philippine biodiesel landscape—showing its 2 % blend policy, production-consumption gap, and reliance on imported diesel to meet national demand.

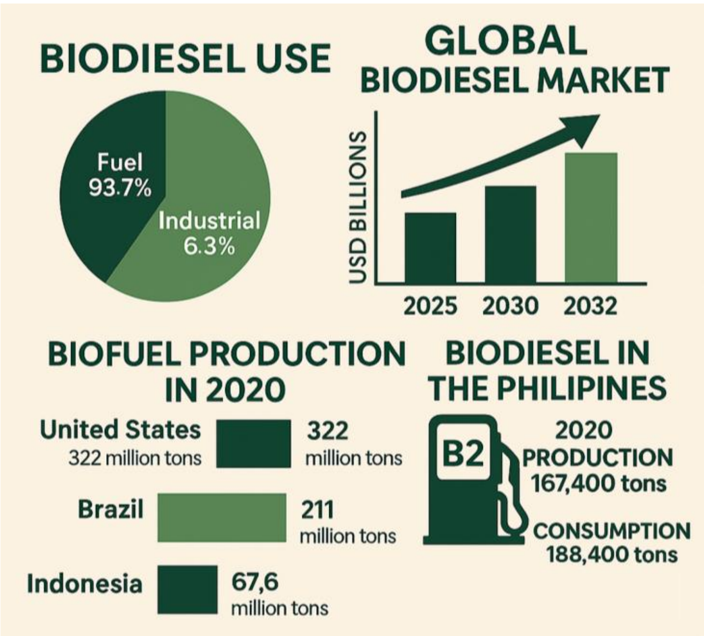

Figure 1: PROMETHEE Simulation Rankings for (a) Process Selection and (b) Plant Location Selection

The global biodiesel market is experiencing steady growth, driven by increasing demand for sustainable energy solutions and the implementation of environmental regulations. According to Persistence Market Research (2024), the global biodiesel market is projected to grow from USD 52.1 billion in 2025 to approximately USD 75.8 billion by 2032, reflecting a compound annual growth rate (CAGR) of 5.5 %. Major regional markets include Europe, Asia, and Latin America, with Europe leading biodiesel consumption, especially in blends ranging from 5 % to 20 %, driven by mandates in countries like Germany, France, and Italy.

In 2020, the United States topped global biofuel production at 1,347.3 Pj (roughly 322 t), followed by Brazil with 883.7 Pj (211 t), and Indonesia at 283 Pj (67.6 t) (U.S. Energy Information Administration, 2020). The U.S.

biodiesel sector has seen consistent growth between 2003 and 2019, supported by federal blending mandates and institutional uptake, including by military sectors (National Biodiesel Board, 2020). Meanwhile, Central and South America are anticipated to record a CAGR of 5.01 % between 2020 and 2030 (ChemAnalyst, 2020).
In the Philippine context, biodiesel production has shown modest yet stable output. According to the USDA Foreign Agricultural Service (FAS), the country produced 220,000 m^3. of biodiesel in both 2018 and 2019, indicating a plateau rather than aggressive growth (USDA FAS, 2019). The mandated blend ratio was fixed at 2 % (B2) from 2009 and remained at that level as of February 2021. Despite policy intentions to implement higher blends, logistical and economic constraints—particularly due to the high cost of coconut oil—prevented their execution.
Despite production stagnation, biodiesel consumption in the Philippines has consistently outpaced local output. In 2020, biodiesel production reached 167,400 t, while consumption totalled 188,400 t, resulting in a domestic shortfall of 21,000 t. Moreover, national diesel consumption was more than double domestic production (9,019,500 t vs. 4,488,100 t), underlining a broader dependence on imports for energy security. These trends underscore the need for policy recalibration and investment in localized production technologies to support energy resilience (Euromonitor International, 2021; USDA FAS, 2019).

3. Technical Study

3.1 Process Selection

Biodiesel can be produced via several technological pathways, with transesterification being the most widely implemented due to its operational simplicity, process efficiency, and scalability. This reaction converts triglycerides—commonly sourced from fats or oils—into fatty acid methyl esters (FAME) and glycerol by reacting with an alcohol, typically methanol or ethanol, in the presence of a catalyst to improve conversion rates (Ma et al., 1999). Transesterification is adaptable to various feedstocks and yields a product comparable to petroleum-derived diesel in fuel characteristics.
The process may be catalyzed through acid, base, or enzyme-based systems. Acid catalysts are suitable for high-FFA feedstocks but are slow and corrosive. Base catalysts, such as sodium hydroxide or potassium hydroxide, are more efficient and cost-effective but are highly sensitive to moisture and FFAs. Enzymatic (lipase-based) catalysts represent an environmentally favorable alternative due to their mild reaction conditions and lower by-product formation, though typically at higher cost and slower reaction rates (Gebremariam and Marchetti, 2017).
To determine the most suitable process route for this study, three transesterification approaches, namely acid catalyzed, base catalyzed, and enzymatic, were comparatively assessed based on criteria including operating conditions, material costs, yield, and waste generation. Table 1 summarizes a few of the key parameters for each route. Selection was facilitated using a Multi-Criteria Decision Aid (MCDA), employing the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) in conjunction with Geometrical Analysis for Interactive Aid (GAIA). This combined method provided both a ranked evaluation and a visual performance map of the alternatives. The resulting analysis identified the base-catalyzed route as the most viable option. Results are shown in Figure 2a. Only the AEBT pathway was simulated in Aspen HYSYS based on the outcome of the PROMETHEE-GAIA analysis and practical considerations excluding enzymatic routes. This approach is consistent with the study by Vo et al. (2021), who simulated a continuous biodiesel production process from crude castor oil using acid pretreatment followed by base-catalyzed transesterification in Aspen HYSYS. Their findings validate the suitability of this hybrid process pathway in biodiesel production modeling.

Table 1: Comparative Parameters of Transesterification-Based Biodiesel Production Processes

Selection Criterion	Base Transesterification Process	Ethylic-enzymatic Transesterification Process	Acid-esterification Base-transesterification Process
Process Yield, %	95.0	90.0	98.3
Raw Materials	Methanol, Sodium Hydroxide	Ethanol, Lipase	Methanol, Sulfuric Acid, Sodium Hydroxide
By-Product Formed	Glycerol	Glycerol	Glycerol

3.2 Plant Location Selection

Plant location is a foundational aspect of process design that significantly affects both capital investment and long-term operability (Towler and Sinnott, 2013). One of the critical early considerations in site selection is the land area required to house the proposed facility and its auxiliary units. To inform this estimation, the newly established JBS Biodiesel plant in Mafra, Santa Catarina, Brazil, was selected as a real-world benchmark.

This facility operates on a land area of 7.6 ha and has a production capacity of approximately 370,000 m^3. annually, which is approximately 326,724 t/y when converted using a biodiesel density of 88,000 kg/m^3., as referenced from EU Knowledge4Policy (2019). The capacity and land area data for this benchmark facility are based on the officially reported expansion of JBS Biodiesel's operations in Mafra, Santa Catarina, which more than doubled the company's total production capacity and demonstrates efficient land utilization in biodiesel plant design (BioBased Diesel, 2023).

Applying this benchmark, the proposed plant—designed for a capacity of 57,742 t/y—would require an estimated land area of approximately 1.34 ha. While this assumes linear scalability and does not yet account for site-specific auxiliary needs such as buffer zones, expansion space, or utilities, it provides a grounded and conservative basis for preliminary spatial planning.

After establishing these land criteria, industrial zones registered with the Philippine Economic Zone Authority (PEZA) were screened for potential locations. These areas were given priority because of their strong infrastructure, advantageous regulatory framework, and convenient access to sources of raw materials and downstream distribution. Three candidate sites were identified: TECO Industrial Park in Mabalacat, Pampanga; Hermosa Ecozone Industrial Park in Hermosa, Bataan; and Cocochem Industrial Park in Bauan, Batangas.

To support the site selection process, a multi-criteria decision analysis (MCDA) was performed using the PROMETHEE-GAIA framework. Evaluation parameters included proximity to feedstock supply chains, land acquisition costs, utility (electricity and water) rates, accessibility via road and port networks, and labor availability. As presented in Figure 2b, Hermosa Ecozone Industrial Park in Bataan emerged as the most viable site based on its integrated performance across all criteria.

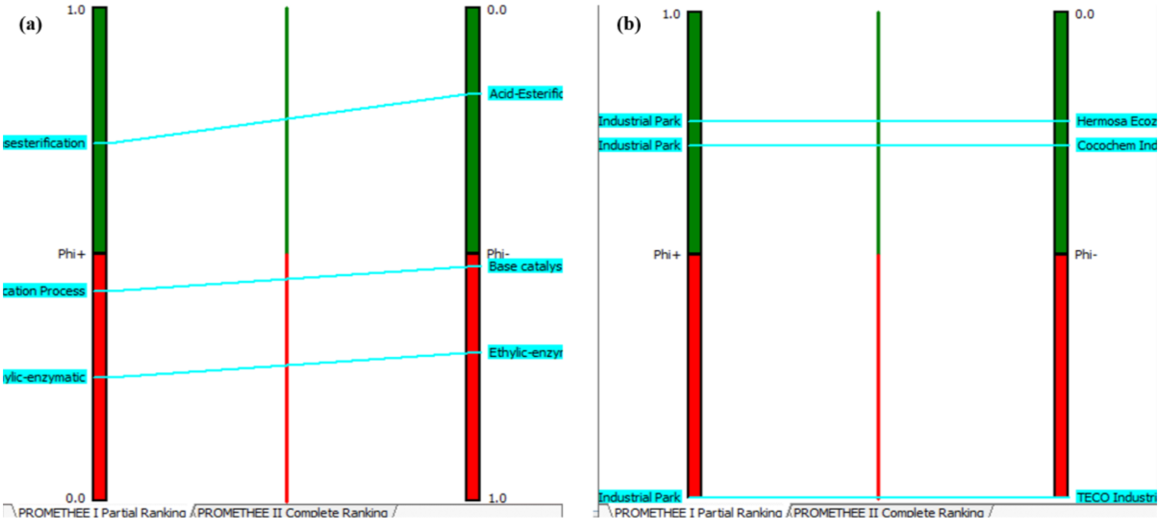

Figure 2: PROMETHEE Simulation Rankings for (a) Process Selection and (b) Plant Location Selection

3.3 Process Specifics

The selected process for this study involves a two-stage conversion pathway consisting of acid-catalyzed esterification followed by base-catalyzed transesterification. This configuration is particularly suited for low-cost, high free fatty acid (FFA) feedstocks such as unrefined rice bran oil and waste frying oil, where direct base catalysis alone would result in soap formation and low yield.

To support and validate the process configuration, simulation approaches from prior literature were reviewed and integrated into model development. Duti et al. (2016) demonstrated the effective use of acid-esterification as a pretreatment step for waste frying oil prior to base-catalyzed transesterification in an Aspen HYSYS environment. This two-step sequence not only improved biodiesel yield but also ensured compliance with ASTM fuel quality standards.

Complementing this, Kattimani et al. (2014) applied a three-stage approach to treat unrefined rice bran oil—initially using two acid-catalyzed esterification steps to reduce FFA levels below 1 %, followed by a base-catalyzed transesterification step. Although more complex, their findings reaffirm the need of acid pretreatment when handling high-FFA feedstocks. Trirahayu (2020) also provided simulation-specific insights using Aspen HYSYS to model the transesterification of rice bran oil. The study included mass and energy balances, methanol recovery, and product separation that were the elements adapted and refined in the present simulation.

Together, these references provided both empirical validation and modeling precedent for the current process design, supporting the decision to adopt a sequential acid-base catalysis route as the most technically and economically appropriate option.

4. Financial Feasibility

The financial performance of the proposed biodiesel production facility was evaluated based on capital investment, operating costs, and projected revenue. As summarized in Table 2, the total fixed capital investment required is PHP9.21 billion. This amount includes costs within the battery limits of the plant, as well as outside battery limit expenses, design and engineering fees, contingency provisions, and land acquisition.

Cost estimates were generated using industry-standard methods based on previous plant data and updated with cost indices that reflect current labor, materials, and energy prices. This approach is consistent with the methodology recommended by Towler and Sinnott (2013), where historical costs are scaled and adjusted to present-day values to guide early-stage design decisions. Operating expenses were divided into variable and fixed costs. Variable costs, primarily from raw material cost, maintenance, taxes, and regulatory fees, amounted to PHP824.39 million. Altogether, the total annual operating cost is PHP7.76 billion. Against this, the projected annual revenue from biodiesel sales is estimated at PHP13.48 billion. This results in a net yearly profit of approximately PHP5.72 billion. The investment is expected to be recovered in less than two y, based on simple payback. This is a favorable result, as typical payback periods for large-scale chemical facilities range from three to five y. The positive cash flow and relatively short recovery period strongly suggest that the project is financially feasible.

In support of this, a net present value (NPV) analysis with a 10-y horizon and a 10 % discount rate yielded a favorable result, showing that future earnings will easily surpass the initial investment.

Table 2: Summary of Overall Plant Costs

Cost	Parameter / Specifics	Value (PHP)	Total (PHP)
Total Fixed Capital Investment	Inside Battery Limit	7,456,917,641.09	9,210,473,175.55
	Outside Battery Limit	163,760,005.20	
	Design and Engineering Cost	762,067,764.63	
	Contingency Charges	762,067,764.63	
	Land Cost	65,660,000.00	
Variable Costs of Production	Raw Materials Expenses	6,055,639,228.00	6,936,035,213.00
	Consumables Expenses	39,212,941.00	
	Electricity Expenses	535,674,305.00	
	Water Cost	9,400,982.00	
	Fuel Cost	83,036,544.00	
	Shipping and Transportation Costs	213,071,213.00	
Total Fixed Cost of Production	Operating Labor Cost	157,199,298.00	824,394,185.70
	Direct Salary Overhead	61,248,000.00	
	Maintenance Cost	528,675,696.00	
	Real Property Tax	2,123,354.29	
	Insurance Cost	74,569,176.41	
	Running License Fees and Permits	388,274.00	
	Telecommunication Expenses	190,387.00	

5. Conclusion

This study successfully demonstrated the technical and financial feasibility of establishing a biodiesel production facility in the Philippines using rice bran oil as feedstock. Simulation of the Acid-Esterification Base-Transesterification process using Aspen HYSYS enabled detailed modeling of the conversion and purification steps across three production sections. Multi-criteria decision analysis using PROMETHEE-GAIA supported the selection of the most viable process route and plant location.

The proposed plant is designed to produce annually 57,742 t of biodiesel. Economic evaluation revealed a net annual profit of PHP5.72 billion, a return on investment of 62.16 %, and a payback period of only 1.61 y, underscoring strong financial viability. Hermosa Ecozone Industrial Park in Bataan emerged as the most suitable site based on land availability, infrastructure, and cost parameters.

These findings support the development of biodiesel infrastructure aligned with the Philippines' commitment to renewable energy, while addressing both economic and environmental objectives under SDGs 7 and 9. Future studies may explore the integration of locally sourced non-edible feedstocks and industrial symbiosis opportunities to further enhance process sustainability and feedstock security.

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