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Economic Analysis of Batch Reactor for Biodiesel Production.

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ABSTRACT

An economic evaluation was conducted for a batch reactor's utilization in producing biodiesel using Jatropha oil, methanol, and sodium hydroxide as a catalyst. The assessment encompassed a fundamental scenario in which the reactor can convert 306.36 metric tons per year of Jatropha oil, methanol, and sodium hydroxide. This setup's computed fixed capital investment amounted to ₦5,795,231.72 million Nigerian Naira, alongside a minimum cost of biodiesel production at ₦ 417.75 per kilogram. The complete capital outlay reached ₦6,817,919.67, yielding a 74% rate of return and a payback period of 1.07 years. The Net Annual Profit after Taxes (NAPAT) was also determined, totalling ₦5,017,979.06. In conclusion, the study confirms the batch reactor's adaptability to various vegetable oils and alcohols for efficient biodiesel production, establishing its economic viability.

1.0 INTRODUCTION

The surge in global population, industrialization, and transportation has led to an upswing in energy demand (Sani et al., 2013). While fossil fuels currently stand as the most abundant energy reservoir, they come with drawbacks like emitting greenhouse gases and the depletion potential, posing a threat to energy security (Kusumaningtyas et al., 2017). Greenhouse gas emissions, primarily caused by these fossil fuels, play a central role in driving global warming and climate change (Nauman Aftab et al., 2019). As a result, it's imperative to curtail the use of fossil fuels and develop a well-structured strategy. It becomes vital to establish alternative, environmentally friendly, and renewable energy solutions to address this concern. Among these alternatives, biodiesel emerges as a highly promising option (Kusumaningtyas et al., 2017). Biodiesel offers numerous benefits such as low sulfur and aromatic content, non-toxic nature, renewability, biodegradability, clean combustion, reduced emissions of greenhouse gases including carbon monoxide, minimized health risks due to lower release of cancer-causing substances, and favorable lubricating properties (Akubude et al., 2021).

Economic expenditures encompass costs linked to employment, labor outlays, pricing of alternative products, and the expenditure on raw materials and energy essential for any industrial operation (Ofori-Boateng & Lee, 2011). The evaluation of costs and benefits is primarily conducted within economic analyses. To enhance the efficient allocation of resources, this process begins by appraising projects based on their economic feasibility. It aims to gauge the impact of a project on overall well-being (Edomah, 2018).

Numerous investigations have been conducted to comprehend the optimal reactor type for addressing technical obstacles in biodiesel production through transesterification. In recent periods, technological approaches or procedures in biodiesel manufacturing have made substantial advancements with the introduction of diverse reactors in varying sizes. Varieties of reactors available include batch reactors, continuously stirred tank reactors, fixed bed reactors, bubble column reactors, microchannel reactors, membrane reactors, reactive distillation, and hybrid catalytic plasma reactors (Akubude et al., 2021). The literature indicates that numerous studies have been conducted to comprehend the economic aspects of various reactors in the biodiesel production process. (El-Galad et al., 2022) examined different pathways for producing biodiesel, incorporating tetrahydrofuran as a co-solvent. The findings revealed that the approach with the lowest total capital investment, net after-tax profit, and the payback period was achieved using this method, specifically with values of M$2.32, M$10.54, and 0.19 years, respectively. Moreover, they attained a remarkable after-tax rate of return of 5.13%. (van Kasteren & Nisworo, 2007) explored the costs associated with manufacturing 8,000 to 125,000 tons of biodiesel annually using a continuous supercritical methanol process and used cooking oil. (You et al., 2008) delved into the economic aspects of a continuous homogeneous alkali-catalyzed process, utilizing soybean oil and producing 8,000 to 100,000 tons of biodiesel annually. Furthermore, (West et al., 2008) analyzed the expenses of producing 8,000 tons of biodiesel per year using four waste cooking oil-based processes: continuous homogeneous alkali-catalyzed, continuous homogeneous acid-catalyzed, continuous heterogeneous acid-catalyzed, and continuous supercritical methanol. Similarly, (Marchetti & Errazu, 2008) calculated the costs of producing 36,036 tons of biodiesel annually using these same four techniques. Among these processes, the continuous heterogeneous acid-catalyzed approach demonstrated the lowest manufacturing costs.

Comprehending the financial ramifications of utilizing batch reactors for biodiesel production is essential from an economic perspective. Despite the widespread use of batch reactors across various industries and educational settings for student practical's, this research specifically focused on evaluating the economic feasibility of a batch designed to manufacture 1000 liters of biodiesel per hour through a cost-benefit analysis.

2.0 BIODIESEL PRODUCTION

Transesterification stands as the predominant technique employed for producing biodiesel using a batch approach, with the operational temperature kept close to the boiling point of alcohol. This process involves the reaction of three moles of methanol with one mole of triglyceride (TG) found in vegetable oils or animal fats. This reaction occurs typically in the presence of a base catalyst, usually NaOH or KOH at a concentration of 0.1-1% relative to the oil. This results in the creation of mono-methyl ester and the simultaneous production of glycerol. To ensure optimal reaction progress, an additional amount of alcohol is commonly used at a 6:1 molar ratio about the oil (Nauman Aftab et al., 2019; Van Gerpen et al., 2004). However, challenges exist within the biodiesel production process using transesterification. These challenges include extended reaction times, elevated operational expenses, inefficient resource utilization, and diminished production efficiency. Recent research efforts in the field of biodiesel synthesis have been directed towards the advancement of process intensification techniques to address these obstacles (Zhang et al., 2003).

3.0 PROCESS DESCRIPTION

Biodiesel is produced through the transesterification of vegetable oil with alcohol using sodium hydroxide as a catalyst. After biodiesel has been produced, the byproduct, such as glycerol, will be drained out using a pump and stored in the glycerol tank. Then water from the water tank will be pumped into the biodiesel in the reactor for a water wash before drying, and finally, it will be stored in the biodiesel tank as shown in Figure 1.

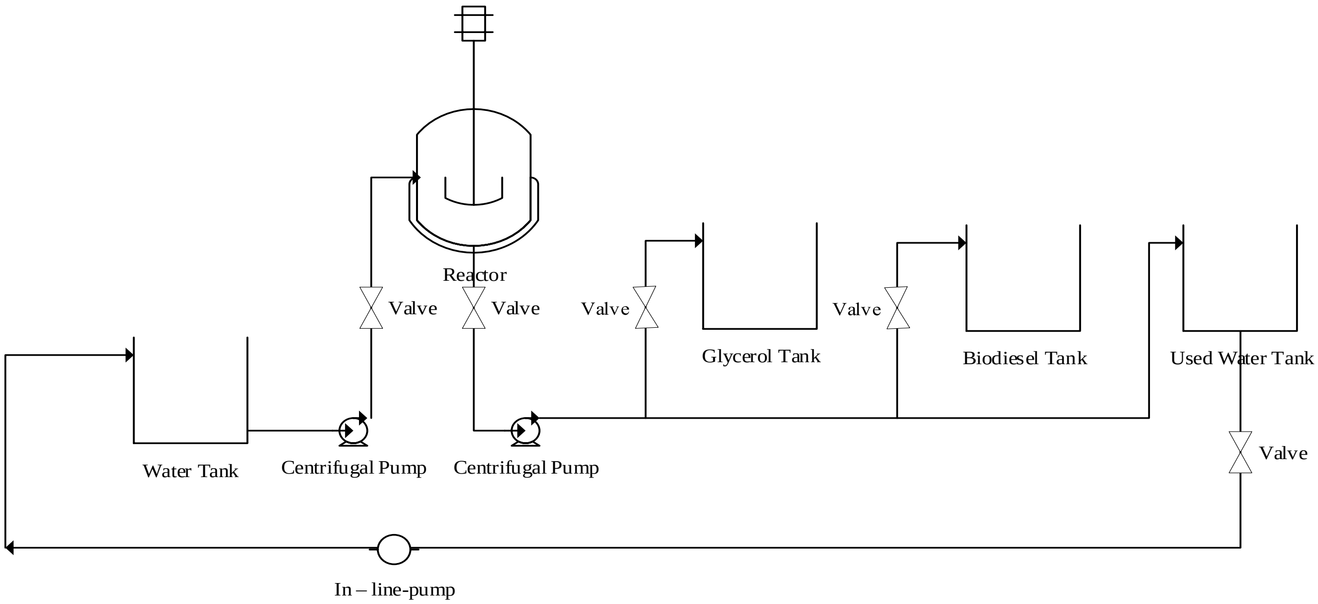

Figure 1 Process Flow Diagram for Biodiesel Production

4.0 ECONOMIC ANALYSIS

The economic analysis essentially entails the evaluation of costs and benefits. It starts by ranking projects based on economic viability to aid better allocation of resources. It aims to analyze the good impact of a project (Cheng et al., 2016).

4.1 Factors for Evaluating Projects

As well as economic performance, many other factors have to be considered when evaluating projects; such as: 1. Safety 2. Environmental problems (waste disposal) 3. Political considerations (government policies) 4. Location of customers and suppliers (supply chain) 5. Availability of labor and support services 6. Corporate growth strategies and 7. Company experience in the particular technology.

4.2 Steps in Economic Analysis of Batch Reactor for Biodiesel Production

Figure 2 depicted steps involve in economic analysis for biodiesel production.

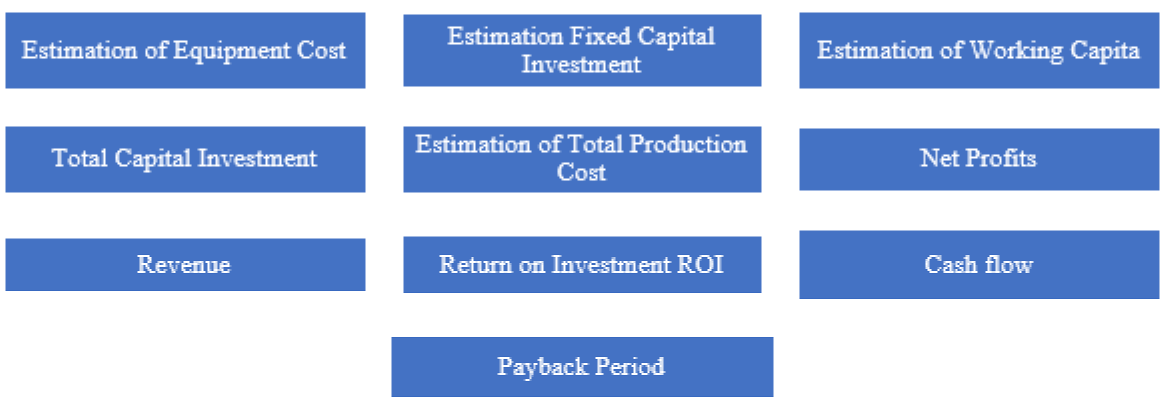

Figure 2 Steps for Economic Analysis of Batch Reactor for Biodiesel Production

4.2.1 Estimation of Equipment Cost

Table 1 depicted the cost of equipment as obtained from different market agencies.

Table 1. Estimation of Equipment Cost

S/N	Equipment	Quantity	Unit Cost (₦)	Equipment Cost (₦)	Source
1	Jacket Agitated Batch Reactor	1	1,058,966.23	1,058,966.23	Alibaba.com
2	1000 Liters PVC Storage Tank	4	65,000	260,000	ATKC
3	1” PVC Pipe(6m)	6	1,800	10,800	ATKC
4	1" PVC Elbow	9	200	1,800	ATKC
5	1" PVC T- Elbow	2	200	400	ATKC
6	1” PVC Valve	5	500	2,500	ATKC
7	Centrifugal Pump	2	35,000	70,000	Jumia.com.ng
8	In-Line-Pump	1	16,873.70	16,873.70	Hyrobuider.com
	Total			**1,420,339.93**	

4.2.2 Estimation of Fixed Capital Investment

Fixed-capital investment (FCI) **is** the capital needed to stream the required manufacturing facilities of the plant (Peters et al., 2003). Table 2 shows the calculated fixed capital investment for this study.

Table 2. Fixed Capital Investment

S/N	Item	Factor	Amount (₦)
1	Equipment	1.00	1,420,339.93
2	Installation	0.50	710,199.97
3	Instrumentation and Control	0.40	568,159.97
4	Piping	0.30	426,119.98
5	Electrical	0.30	426,119.98
6	Buildings, Process, and Auxiliary	0.60	852,239.96
7	Service Facilities and Land Improvement	0.60	852,239.958
8	Land	0.08	113,631.99
9	Engineering and Supervision	0.05	71,020.00
10	Legal Expenses	0.03	42,612.00
11	Construction Expenses and Contractor’s Fee	0.11	156,243.99
12	Contingency	0.11	156,243.99
	Total		**5,795,231.72**

Source of Factor: (Peters et al., 2003)

4.2.3 Estimation of Working Capital

Working capital (WC) represents the funds necessary to sustain plant operations, encompassing various components: inventory of raw materials and supplies, stocks of finished and partially manufactured goods, outstanding payments from customers (reflecting approximately one month’s production cost), cash allocated for monthly operating payments like salaries, wages, and raw material procurement, as well as liabilities like accounts payable and taxes due. Consequently, working capital is calculated as 15% of the total capital cost (Peters et al., 2003).

4.2.4 Estimation of Total Capital Investment

Most estimates of capital investment are based on the cost of the equipment required, total capital investment is the sum of the fixed-capital investment and the working capital (Peters et al., 2003).

Total Capital Investment = Fixed-capital Investment + Working capital 4.1

Total Capital Investment **= ₦6,817,919.67**
Working Capital = **₦1,022,687.95**

4.2.5 Estimation of Total Production Cost

Total Production Cost is the total of all costs of operating the plant, selling the products, recovering the capital investment, and contributing to corporate functions such as management and research and development (Peters et al., 2003) as revealed in table 3.

Table 3. Total Production Cost

S/N	Item	Factor	Amount (₦)
1	Raw Materials	0.110	10,889,581.29
2	Operating Labor	0.100	9,899,619.36
3	Direct Supervisory and Clerical Labor	0.010	989,961.94
4	Electricity	0.200	19,799,238.71
5	Fuel	0.200	19,799,238.71
6	Water	0.200	19,799,238.71
7	Maintenance and Repair	0.100	579,523.17
8	Operating Supplies	0.030	173,856.95
9	Laboratory Charges	0.010	989,961.94
10	Depreciation	0.200	1,363,583.93
11	Local Taxes	0.010	57,952.32
12	Insurance	0.040	231,809.27
13	Financing (Interest)	0.010	68,179.20
14	Over Head Cost	0.053	5,246,798.26
15	Administrative Cost	0.022	2,177,916.26
16	Distribution and Marketing	0.020	1,979,923.87
17	Research and Development	0.050	4,949,809.88
	Total		**98,996,193.56**

Source of Factor: (Peters et al., 2003)

4.2.6 Calculating Revenue

Revenue is generated from the sale of the product or products produced by the plant. The total annual revenue from product sales is the sum of the unit price of each product multiplied by its rate of sales (Peters et al., 2003) as shown in table 4.

$$\text{Annual sales revenue}, \frac{₦}{\text{yr}} = \sum(\text{sales of product, kg/yr}) \;\; x \;\; (\text{product sales price, ₦/kg}) \qquad 4.2$$

Table 4. Annual Sales Revenue

S/N	Parameters	Unit	Value
1`	Price of Biodiesel (Rs75/kg) *	₦	417.75
2	Price of Glycerol (Rs 50/kg) *	₦	278.50
3	Number of Days of Production in a Year	days	276
4	Biodiesel Produced	kg/yr	276,000
5	Glycerol Produced	kg/yr	29,278.08
6	Sale of Biodiesel	₦/kg	99,925,800.00
7	Sale of Glycerol	₦/kg	8,153,945.27
	Total Annual Sales Revenue	**₦/yr**	**108,079,745.28**

Source: Indian Market, 2022*

1 Rs Equivalent to 5.57 Nigerian Naira (₦)

4.2.7 Depreciation

Depreciation stands out as a unique expense as it involves allocating funds to the company's treasury. The underlying idea of depreciation revolves around the recognition that physical assets degrade and lose value over time, leading to a decline in their worth. This decline in value is termed as physical depreciation and signifies the reduction in the value of an asset due to alterations in its physical attributes. Factors like wear and tear, corrosion, accidents, and the natural effects of time all contribute to physical depreciation. Such depreciation diminishes the functionality of the asset due to these physical changes. On the other hand, functional depreciation encompasses all other reasons for an asset's value decline. A notable example of functional depreciation is obsolescence, which occurs when technological advancements render an existing asset outdated. Other causes for functional depreciation include a decrease in demand for the asset's services, shifts in population, alterations in public authority requirements, inadequate capacity, and the abandonment of the enterprise (Peters et al., 2003). The calculation of depreciation can be achieved using equation 4.3.

$$D = \frac{I}{L} \qquad 4.3$$

Where D = Annual Depreciation, I = Original Investment, and L = Length of Straight-line recovery period.

4.2.8 Return on Investment ROI

Return on investment is a performance measure used to evaluate the efficiency or profitability of an investment or compare the efficiency of several different investments (Max *et al*., 2003).

Gross Annual Profit = Sales – Operating Cost – Depreciation 4.4

Sales per year = The Number of Items Sold Times the Price per Item 4.5

Net Annual Profit after Taxes (NAPAT) = $(1 - \phi)\ x\ Gross\ Annual\ Profit$ 4.6

$\phi = \text{FractionalIncome Tax Rate}$

$$\boldsymbol{ROI} = \frac{NAPAT}{Total\ Capital\ Investment} \qquad 4.7$$

4.2.9 Cash flow

Cash flow is the amount of funds that enter the corporate treasury as a result of the activities of the project (Peters et al., 2003).

Cash flow = Net Annual Profits after Tax + Depreciation 4.8

4.2.10 Payback Period

The payback period is defined as the number of years required to recover the original cash investment. In other words, it is the period at the end of which a machine, facility, or other investment has produced sufficient net revenue to recover its investment costs (Kiran, 2022; Peters et al., 2003).

A simple method for estimating the pay-back time is to divide the total initial capital (fixed capital plus working capital) by the average annual cash flow:

$$\text{Simple Payback Time} = \frac{\text{Total Investment}}{Average\ Annual\ Cash\ Flow} \qquad 4.9$$

Table 5. Profitability

S/N	Parameter	Unit	Value
1	Total Annual Sales	₦	108,079,745.28
2	Total Production Cost	₦	98,996,193.56
3	Income Tax Rate	%	35
4	Total Capital Investment	₦	6,817,631.66
5	Gross Annual Profit	₦	7,719,967.79
6	Net Annual Profit After Taxes (NAPAT)	₦	5,017,979.06
7	Depreciation	₦	1,363,583.93
8	Return on Investment ROI	Per years	74%
9	Cash flow	₦	6,381,562.99
10	Payback Period	Years	1.07

5.0 SENSITIVITY ANALYSIS

5.1 Simple Sensitivity Analysis

Sensitivity analysis involves investigating the impact of uncertainties in forecasts on a project's feasibility. Initially, the total investment cost and cash flows were computed using specific values for different factors, creating a baseline for analysis. These values were outlined in Sections 4.2.4 and 4.2.9 and are also displayed in Table 5. Adjustments were made to the prices of biodiesel and glycerol, as indicated in Table 6. These adjustments reveal those changes in price influence both cash flow and project profitability. This highlights how vulnerable cash flows and economic metrics are to inaccuracies in forecasted figures. Conducting a sensitivity analysis provides insight into the level of risk associated with evaluating the project's forecasted performance.

Table 6. Sensitivity Analysis

S/N	Price of Products (₦)	Sale of Biodiesel (₦)	Sale of Glycerol (₦)	Total Sale (₦)	GAP (₦)	NAPAT (₦)
1	111.40	30746400	3261578	34007978	-66351798	-43128669
2	139.25	38433000	4076973	42509973	-57849804	-37602373
3	167.10	46119600	4892367	51011967	-49347809	-32076076
4	194.95	53806200	5707762	59513962	-40845815	-26549780
5	222.80	61492800	6523156	68015956	-32343820	-21023483
6	250.65	69179400	7338551	76517951	-23841826	-15497187
7	278.50	76866000	8153945	85019945	-15339831	-9970890
8	305.35	84276600	8940062	93216662	-7143115	-4643025
9	334.20	92239200	9784734	1.02E+08	1664157.8	1081702.6
10	362.05	99925800	10600129	1.11E+08	10166152	6607999
11	389.90	1.08E+08	11415523	1.19E+08	18668147	12134295
12	417.75	1.15E+08	12230918	1.28E+08	27170141	17660592
13	445.60	1.23E+08	13046312	1.36E+08	35672136	23186888
14	473.45	1.31E+08	13861707	1.45E+08	44174130	28713185
15	501.30	1.38E+08	14677102	1.53E+08	52676125	34239481
16	529.15	1.46E+08	15492496	1.62E+08	61178119	39765778
17	557.00	1.54E+08	16307891	1.7E+08	69680114	45292074

GAP = Gross Annual Profit
NAPAT = Net Annual Profit After Taxes

6.0 CONCLUSIONS

The objectives of this study were successfully met, yielding the subsequent outcomes, which encompass: evaluation of equipment expenses totaling ₦1,420,339.93, assessment of working capitals amounting to ₦1,022,687.95, determination of fixed capital investment valued at ₦5,795,231.72, resulting in an overall capital investment of ₦6,817,919.67. Furthermore, there was an estimation of total production costs reaching ₦98,996,193.56, accompanied by revenue of ₦110,079,745.28. After-tax profits were measured at ₦5,017,979.06. The return on investment (ROI) stood at 74% annually, with a payback period of 1.07 years. The cash flow amounted to ₦6,381,562.99. In conclusion, the study demonstrates that the batch reactor can accommodate a variety of vegetable oils and alcohols for biodiesel production. Economically, the project's feasibility is evident, as revealed by sensitivity analysis. This analysis indicates that changes in biodiesel and glycerol prices have a significant impact on project cash flow and profitability, further affirming the project's viability.

REFERENCES

AIS Nigeria Trading Services. https://nigeria.tradeford.com.

Akubude, V. C., Jaiyeoba, K. F., Oyewusi, T. F., Abbah, E. C., Oyedokun, J. A., & Okafor, V. C. (2021). Overview of Different Reactors for Biodiesel Production. *Biodiesel Technology and Applications*, 341–359. https://doi.org/10.1002/9781119724957.ch12.

ATKC Hardware Trading Sdn Bhd, "ATKC e-Commerce Warehouse Online Store," (2021). [Online]. Available: https://www.ewarehouse.atkc.com.my/.

Cheng, Y. S., Fung, K. Y., Ng, K. M., & Wibowo, C. (2016). Economic analysis in product design - A TCM dietary supplement case study. *Chinese Journal of Chemical Engineering*, *24*(1), 202–214. https://doi.org/10.1016/j.cjche.2015.06.014.

Edomah, N. (2018). Economics of Energy Supply. *Reference Module in Earth Systems and Environmental Sciences*, 0–16. https://doi.org/10.1016/b978-0-12-409548-9.11713-0.

El-Galad, M. I., El-Khatib, K. M., & El-Sheltawy, S. T. (2022). Techno-economic and Sensitivity Analyses of Different Biodiesel Production Pathways by Adding Tetrahydrofuran as a Cosolvent. *Bioenergy Research*, *16*(1), 550–564. https://doi.org/10.1007/s12155-022-10423-3.

Kiran, D. R. (2022). Principles of Economics and Management for Manufacturing Engineering. *Principles of Economics and Management for Manufacturing Engineering*, 1–299.

https://doi.org/10.1016/B978-0-323-99862-8.09985-4.

Kusumaningtyas, R. D., Ratrianti, N., Purnamasari, I., & Budiman, A. (2017). Kinetics study of Jatropha oil esterification with ethanol in the presence of tin (II) chloride catalyst for biodiesel production. *AIP Conference Proceedings*, *1788*(January). https://doi.org/10.1063/1.4968339.

Marchetti, J. M., & Errazu, A. F. (2008). Technoeconomic study of supercritical biodiesel production plant. *Energy Conversion and Management*, *49*(8), 2160–2164. https://doi.org/10.1016/j.enconman.2008.02.002.

Nauman Aftab, M., Iqbal, I., Riaz, F., Karadag, A., & Tabatabaei, M. (2019). Different Pretreatment Methods of Lignocellulosic Biomass for Use in Biofuel Production. *Biomass for Bioenergy - Recent Trends and Future Challenges*, 1–25. https://doi.org/10.5772/intechopen.84995.

Ofori-Boateng, C., & Lee, K. T. (2011). Feasibility of Jatropha Oil for Biodiesel: Economic Analysis. *Proceedings of the World Renewable Energy Congress – Sweden, 8–13 May 2011, Linköping, Sweden*, *57*, 463–470. https://doi.org/10.3384/ecp11057463.

Peters, M. S., Timmerhaus, K. D., & West, R. E. (2003). Plant Design and Economics for Chemical Engineers 5th Edition. In *Journal of Petrology* (Vol. 369, Issue 1). http://repository.um-palembang.ac.id/id/eprint/9024/1/Plant Design and Economics for Chemical Engineers %28 PDFDrive.com %29.pdf.

Sani, Y. M., Daud, W. M. A. W., & Abdul Aziz, A. R. (2013). Solid acid-catalyzed biodiesel production from microalgal oil - The dual advantage. *Journal of Environmental Chemical Engineering*, *1*(3), 113–121. https://doi.org/10.1016/j.jece.2013.04.006.

Van Gerpen, J., Shanks, B., Pruszko, R., Clements, D., & Knothe, G. (2004). Biodiesel Analytical Methods. *Nrel/Sr-510-36240*, *August 2002-January 2004*, 100. http://www.nrel.gov/docs/fy04osti/36240.pdf.

van Kasteren, J. M. N., & Nisworo, A. P. (2007). A process model to estimate the cost of industrial-scale biodiesel production from waste cooking oil by supercritical transesterification. *Resources, Conservation and Recycling*, *50*(4), 442–458. https://doi.org/10.1016/j.resconrec.2006.07.005.

West, A. H., Posarac, D., & Ellis, N. (2008). Assessment of four biodiesel production processes using HYSYS.Plant. *Bioresource Technology*, *99*(14), 6587–6601. https://doi.org/10.1016/j.biortech.2007.11.046.

You, Y. Der, Shie, J. L., Chang, C. Y., Huang, S. H., Pai, C. Y., Yu, Y. H., & Chang, C. H. (2008). Economic cost analysis of biodiesel production: Case in soybean oil. *Energy and Fuels*, *22*(1), 182–189. https://doi.org/10.1021/ef700295c.

Zhang, Y., Dubé, M. A., McLean, D. D., & Kates, M. (2003). Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis. *Bioresource Technology*, *90*(3), 229–240. https://doi.org/10.1016/S0960-8524(03)00150-0.

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