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Commercialization Analysis of POME (Palm Oil Mill Effluent) With AOP (Advance Oxidation Process) Nanobubble Using Business Model Canvas

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Abstract

Indonesia is the largest CPO producer in the world, where around 59.1% or more than half of the world's palm oil market needs are produced by Indonesia or as much as 45.5 million tons in 2023. From the production of oil palm plantations, about 50% is wastewater known as POME (Palm Oil Mill Effluent). The release of POME into the environment can cause environmental problems such as water and soil pollution that causes damage to aquatic ecosystems and eutrophication, in addition to air pollution due to carbon dioxide, methane and hydrogen sulfide gases which are the main causes of climate change. The Indonesian government is committed to reducing gas emissions by 29% by 2030, so the government issued Permentan No. 38 of 2020 concerning Indonesian Sustainable Palm Oil (ISPO) to ensure the creation of sustainability standards for the palm oil industry in Indonesia. Effort that can be made by the palm oil industry to support government programs is by processing POME that must adjust the waste management criteria determined by the RSPO. One way that can be applied in POME treatment is to use nanobubble AOP technology for wastewater treatment that will be released to the environment because of its ability to remove various types of contaminants without using chemicals in wastewater treatment. The objective of this study is to analyze the commercial feasibility of POME treatment using nanobubble AOP technology. The method used in assessing the feasibility of POME processing is the Business Model Canvas (BMC) which considers the Payback Period (PP), Return On Investment (ROI), and Internal Rate of Return (IRR) values. Based on the calculation results, POME processing is feasible to commercialize with the revenue value coming from two main activities, namely water re-use processing and converting waste into organic fertilizer, which will produce a PP value of 1 year and 4 months, an ROI value of 64,22%, and an IRR value of 65,85%.

Keywords
POME commercialization, RSPO, Advanced Oxidation Process, Water Reuse, Business Model Canvas

1. Introduction
Based on the Commodity Intelligence Report compiled by the United States Department of Agriculture (USDA), Indonesia is named the world's largest producer and supplier of palm oil, reaching 59.1% of the world's total palm oil demand, or 46 million tons in 2023 (United State Department of Agriculture, 2023). The total area of oil palm plantations in Indonesia in 2024 has reached 15.434 million hectares, with a national average productivity level of 3.36 tons/ha/year (BPS, 2024; SPKS, 2024). For Indonesia, the palm oil industry also plays an important role as the largest export commodity, reaching a value of $28.6 billion (Direktorat Jendral Perkebunan, 2023). In addition to the agricultural sector, palm oil has also played a role in the energy sector, where it has been developed into vehicle fuel, namely biodiesel, since 2006, supported by Government Regulation No. 32/2006 (Sipayung, 2024). The production of oil palm Fresh Fruit Bunches (FFB), which will later be processed into Crude Palm Oil (CPO), solid waste, and

liquid waste. Solid waste produced by oil palm is generally in the form of Empty Palm Fruit bundles, fibre, shells, wet decanter solids, and boiler ash. As for liquid waste in the form of wastewater, residual oil, and solid content, it is often referred to as Palm Oil Mill Effluent (POME), whose percentage reaches 50%, or around 2.5 to 3.37 tons of POME for every one-ton of FFB (Simanjuntak et al., 2016; Winrock International, 2021). POME cannot be released freely into the environment because it contains harmful substances that can cause water and soil pollution, leading to eutrophication and air pollution. POME contains carbon dioxide, hydrogen sulfide, and methane gases that contribute to greenhouse gas emissions of approximately 12.4 million tons per year (Winrock International, 2021).

The government has launched a National Strategic Program that requires the palm oil industry to prioritize environmental, social, and corporate governance impacts, and Indonesia has committed to reducing emissions with a target of 29% by 2030 (Kementrian Lingkungan Hidup, 2016; Perkebunan Nusantara, 2023). Therefore, the government designed a policy related to the Indonesia Sustainable Palm Oil (ISPO) standard written in MOA Number 38 of 2020 as an effort to reduce emissions and succeed the government program (Menteri Pertanian Republik Indonesia, 2020). One of the efforts that can be made to improve the sustainability of the palm oil industry is not only by improving the palm oil processing process but also through waste management, especially liquid waste or POME. POME management has been determined to conform to the sustainability standards set by the Roundtable on Sustainable Palm Oil (RSPO) in the waste management criteria which demands avoiding contamination of surface water and groundwater through soil runoff, nutrients or chemicals, or as a result of waste disposal including POME (RSPO, 2007).

Generally, POME treatment is carried out in open ponds under anaerobic conditions involving several different groups of microorganisms (Winrock International, 2021). Another alternative that can be used for POME management is the Advanced Oxidation Process (AOP) Nanobubble method which is also commonly used in wastewater treatment (Deng & Zhao, 2015; Yulia & Meilina, 2016). AOP is a method of oxidation and removal of contaminants from water using free radicals such as hydroxyl radicals (-OH) by oxidizing various types of contaminants, including organic compounds, heavy metals, and microorganisms (Deng & Zhao, 2015). Meanwhile, nanobubbles are very small gas bubbles with a diameter of less than 200 nanometers that form in liquids that can improve water quality, remove pollutants, and increase oxygen levels in water (Yusuf & Nanda, 2023). By combining AOP and nanobubbles, this technology can provide a more effective and environmentally friendly solution in water treatment (Hutagalung et al., 2023). AOP nanobubble is used to reduce Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS) levels in POME (Yulia & Meilina, 2016).

Apart from the palm oil industry, nanobubble AOP has been applied in various other industries such as textile and paper, but this technology is still very rarely applied in Indonesia due to high initial investment costs (Hutagalung et al., 2020, 2023; Ristiawan & Syafila, 2015; Winrock International, 2021). Therefore, this study aims to analyze the feasibility of commercializing nanobubble AOP technology, especially in the palm oil industry. Business Model Canvas is used to analyze components including key partners, key activities, key resources, value proposition, customer relations, channels, customer segments, cost structure, and revenue streams. Meanwhile, to assess the investment feasibility of AOP in this study using the calculation of the Payback Period (PP), Return of Investment (ROI), and Internal Rate of Return (IRR).

The background explanation of this research has been explained in the first section, section two will explain some of the literature review used to support this research. The third section explains the research methods used, the fourth section discusses the results of business model canvas processing and feasibility analysis, the last section discusses the conclusions of this research.

2. Literature Review

2.1. Palm Oil Mill Effluent (POME)

Palm Oil Mill Effluent (POME) poses a significant environmental threat due to its high levels of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD), which can harm aquatic ecosystems by reducing dissolved oxygen levels (Maryani & Umar, 2021). Produced in large quantities during palm oil processing—about 2.5 to 3 cubic meters per ton of crude palm oil (CPO)—POME is rich in organic matter, with COD, BOD, and Total Suspended Solids (TSS) reaching 1600 mg/L, 160 mg/L, and 14,787 mg/L, respectively (Maryani & Umar, 2021). Effective management of POME involves various treatment technologies, such as anaerobic digestion, which can reduce BOD by up to 95% while producing biogas for renewable energy, and photocatalytic degradation using titanium dioxide

(TiO2) to tackle recalcitrant pollutants (Yong et al., 2023). Optimization of these processes through methods like response surface methodology (RSM) can enhance efficiency, maximize biogas production, and reduce pollutant discharge. Despite advancements, challenges like POME's high organic load and the economic feasibility of treatments, especially in regions reliant on low-cost open pond systems, persist (Igwe & Onyegbado, 2007). Future research should explore integrated treatment approaches, such as combining biological and photocatalytic methods to achieve zero liquid discharge (ZLD), and the use of biosensors for monitoring POME levels. Addressing these challenges with innovative solutions can help mitigate the environmental impact of palm oil production and support the industry's sustainable development (Maryani & Umar, 2021).

2.2. Sustainable Palm Oil Industry Regulation (ISPO and RSPO)

The sustainable palm oil industry is both an international issue and a spectacular environmental and social phenomenon, confirming two major certification schemes-the Indonesian Sustainable Palm Oil and the Roundtable on Sustainable Palm Oil (Pareira, 2023). The ISPO, initiated in 2011 by the Indonesian government, is a compulsory certification scheme concerning legal compliance, sustainability, and addressing land ownership and practices of the small-hold farmers. Though obligatory, ISPO has run at a weak enforcement, conflicting regulations, and a scope of limited authority thus very ineffective. Contrastingly, RSPO was established in 2004 as a voluntary but aimed at achieving sustainability through basic requirements on environmental, social and economic needs (Husin et al., 2023). RSPO is, however, an international regulating which is voluntarily and involves expensive certification mainly for the small holders and henceforth impeded the popularity of this certification in Indonesia. The weaknesses include a legal framework of the ISPO, in addition to RSPO global recognition, which is one of two good reasons to avoid it (Pareira, 2023). Both schemes will incur mutual benefits for the stakeholders in terms of increased traceability and sustainability standards upon harmonization of the certification scheme. Land-related issues, involvement of small-stakes, and coordination of regulation are among the issues that need to be tackled with a clear view towards the future of the billion-dollar mainstream palm oil industry.

2.3. Advance Oxidation Process (AOP)

Advanced Oxidation Processes (AOPs) have emerged as a vital technology in the treatment of water and wastewater, owing to their capacity to degrade a broad spectrum of organic pollutants and microbial contaminants through the in-situ generation of highly reactive oxidizing species, such as hydroxyl radicals. These processes encompass a range of methods, including ozonation, Fenton and photo-Fenton reactions, heterogeneous photocatalysis, and UV-based treatments utilizing hydrogen peroxide (H_2O_2) or ozone (O_3) (Hübner et al., 2024). Recent advancements in AOPs have focused on the development of catalytic and ozone-based processes, which demonstrate significant potential in the treatment of industrial and pharmaceutical wastewater. Moreover, photocatalysis and photo-Fenton processes have been identified as effective tertiary treatments, particularly for the detoxification of micropollutants and microbial contaminants, including viruses. UV/H_2O_2 and UV/O_3 treatments have also garnered extensive research attention for their efficacy in degrading organic pollutants across various wastewater treatment scenarios, such as textile effluents and volatile organic compounds (VOCs) (Garrido-Cardenas et al., 2020). However, despite the proven effectiveness of AOPs, several challenges persist, particularly in terms of scalability and cost. The production of ferrous sludge associated with Fenton processes, coupled with the high costs of H_2O_2 and O_3, presents significant barriers to widespread adoption (Kokkinos et al., 2021). To address these issues, the integration of multiple AOPs and the optimization of process design are critical. Furthermore, the removal of emerging contaminants, such as antibiotics and antibiotic-resistant bacteria, remains an area requiring further investigation to ensure the safe reuse of treated wastewater (Garrido-Cardenas et al., 2020). The absence of standardized experimental protocols for AOPs also impedes the comparability and scalability of research findings, underscoring the need for a systematic approach to the evaluation of these processes. Figure 1 below illustrates the scheme of POME effluent management using AOP Nanobubble technology.

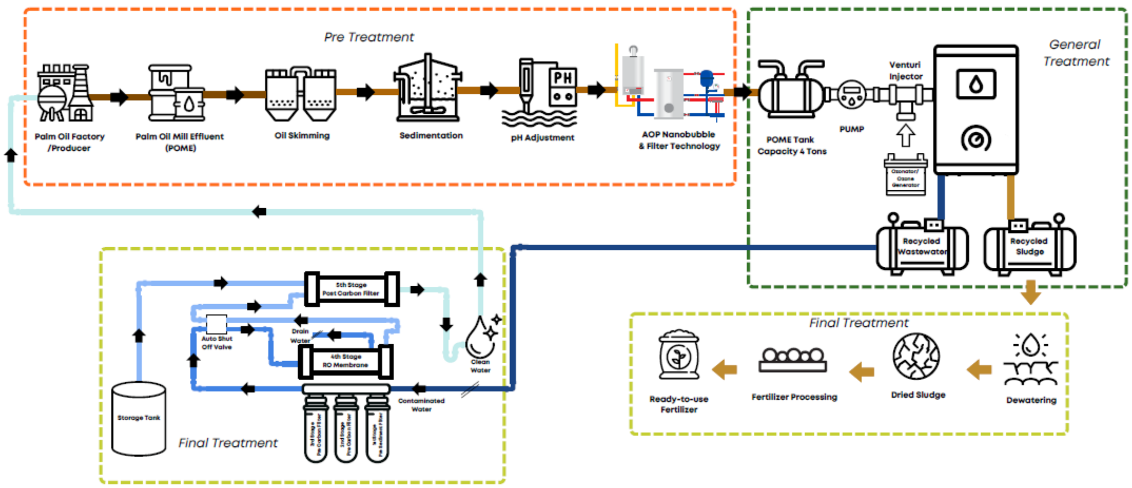

Figure 1. Flow Process of Waterwaste (POME) Management use AOP Nanobubble

2.4. Business Model Canvas (BMC)

A business model is a description of how a company creates added value in the world of work, including a combination of products, services, image, distribution resources and infrastructure (Hermawan & Pravitasi, 2013). The purpose of the business model concept has been defined by emphasizing value creation as part of managing technology development (Hermawan & Pravitasi, 2013). According to Osterwalder & Pigneur (2010) creating a business model framework in the form of a canvas containing interrelated elements will allow business people to understand the business model so that they can easily communicate the company's business model to others and at the same time learn about business opportunities. The nine blocks are depicted in Figure 2, covering four main areas of business: customers, offerings, infrastructure, and financial viability.

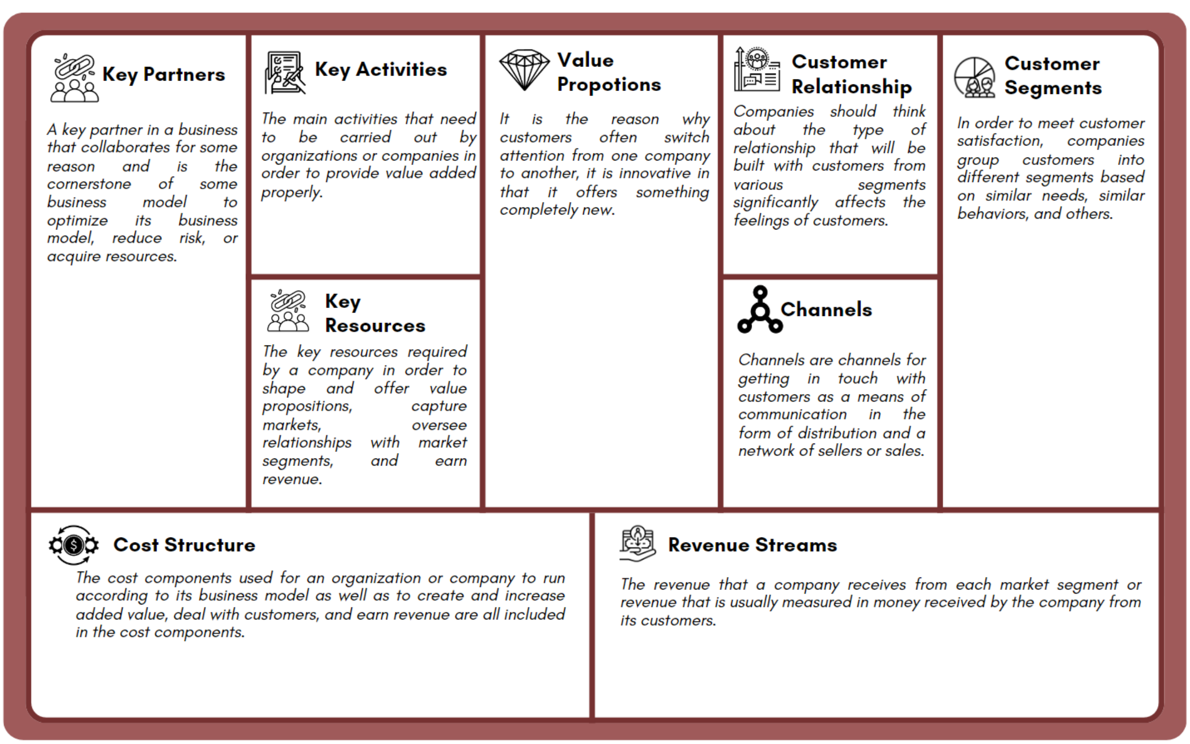

Figure 2. Business Model Canvas Method

2.5. Economic Feasibility
Technology investment feasibility analysis can be measured in the following ways.

a. Internal Rate of Return

IRR is the discount rate in condition where the NPV equal to zero. This method measures the rate of return generated by an investment. If the internal rate of return exceeds the minimum discount rate set, then the project is acceptable. IRR measures the rate of return generated by a project (Sinaga et al., 2023).

b. Return on Investment

ROI is expressed to measure the amount of return on a particular investment against the cost of the investment. The return on investment is divided by the cost of the investment and the result is expressed as a percentage or ratio. ROI is usually used as an index to measure performance and evaluate the efficiency of investments in a project or initiative or compare the efficiency of a number of different investments(Hassanzadeh & Bigdeli, 2020).

c. Payback Period

Payback period is the period of time required to recover the cost of an investment based on net cash flow. The payback method is often used as a rough guide to cost effectiveness. Projects with short payback periods are considered to have lower risk (Sinaga et al., 2023).

3. Methods
The commercial feasibility analysis of POME treatment with nanobubble AOP technology was conducted using the Business Model Canvas (BMC) and considering the PP, ROI, and IRR calculations shown in Figure 3.

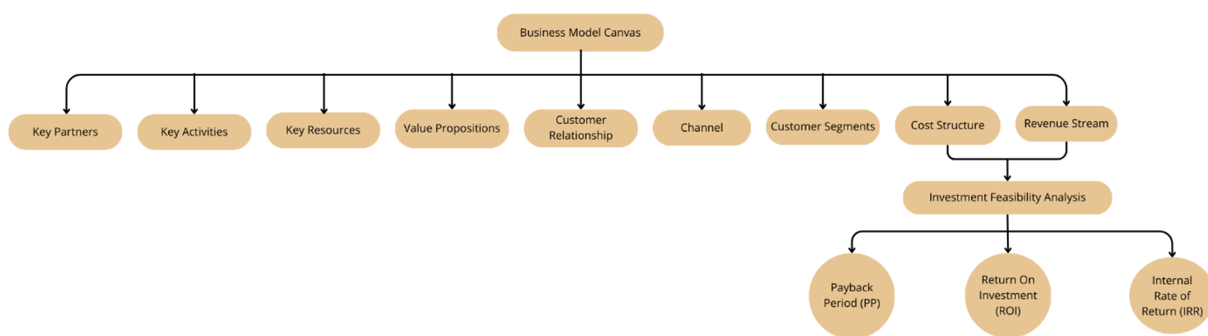

Figure 3. Commercialization Feasibility Analysis Methodology

This research begins with the identification of problems that arise in the palm oil industry in the form of POME which has the aim of water reuse processing and converting waste into organic fertilizer. The next step is to conduct a literature review related to POME, alternative POME processing methods, POME standards in ISPO and RSPO and an analysis of the feasibility of commercializing POME processing. After that, determine the technology that is the solution to the POME problem in the palm oil industry where the technology used is AOP Nanobubble. The last stage is to analyze the feasibility of commercializing POME processing using AOP Nanobubble technology using BMC and consider the calculation of PP, ROI, and IRR with the following calculations (Agung & Zuhri, 2023; Hassanzadeh & Bigdeli, 2020).

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} - C_O \quad (1)$$

Where,

NPV : Net Present Value

C_t : Cash flow in t-year

C_o : Cash outflow / Initial investment

t : year

n : investment age (year)

i : interest rate

$$\mathrm{IRR} = i1 + (i2 - i1) \times \frac{\mathrm{NPV1}}{(\mathrm{NPV1} - \mathrm{NPV2})} \quad (2)$$

Where,
IRR : Internal Rate of Return
i1 : Interest rate NPV positive
i2 : Interest rate NPV negative
NPV1: NPV positive
NPV2: NPV negative

$$PP = n + \left(\frac{a-b}{c-b}\right) \text{ x 1 tahun} \quad (3)$$

Where,
PP : Payback Period
a : investment amount
b : cumulative amount of net cash in the n year
c : cumulative amount of net cash in year n+1

$$ROI = \frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}} \times 100\% \quad (4)$$

The data used is secondary data as follows:
1. POME content includes 95-96% water, 0.6-0.7% oil, and 4-5% fat and solids (Yonas et al., 2012);
2. The volume of POME produced is assumed to reach 40 tons per day;
3. The content in 100 tons of POME contains an average amount of; 55 kg of nitrogen, 9 kg of phosphate, and 85 kg of potassium (Wahyuni, 2018);
4. The time required in 1 processing cycle using AOP based on machine specifications is 1.5 hours;
5. The efficiency of water separation using Nanobubble AOP is 95%;
6. Fertilizer selling price using 50% of the market selling price;
7. Labor costs and utilities are assumed to increase by 10% and 5% respectively every year.

4. Results and Discussion
4.1 Business Model Canvas
The following is an analysis using the business model canvas for POME processing using the nanobubble AOP method on the components of key partners, key activities, key resources, value prepositions, customer relationships, channels, customer segments, cost structure, revenue streams illustrated in Figure 4.

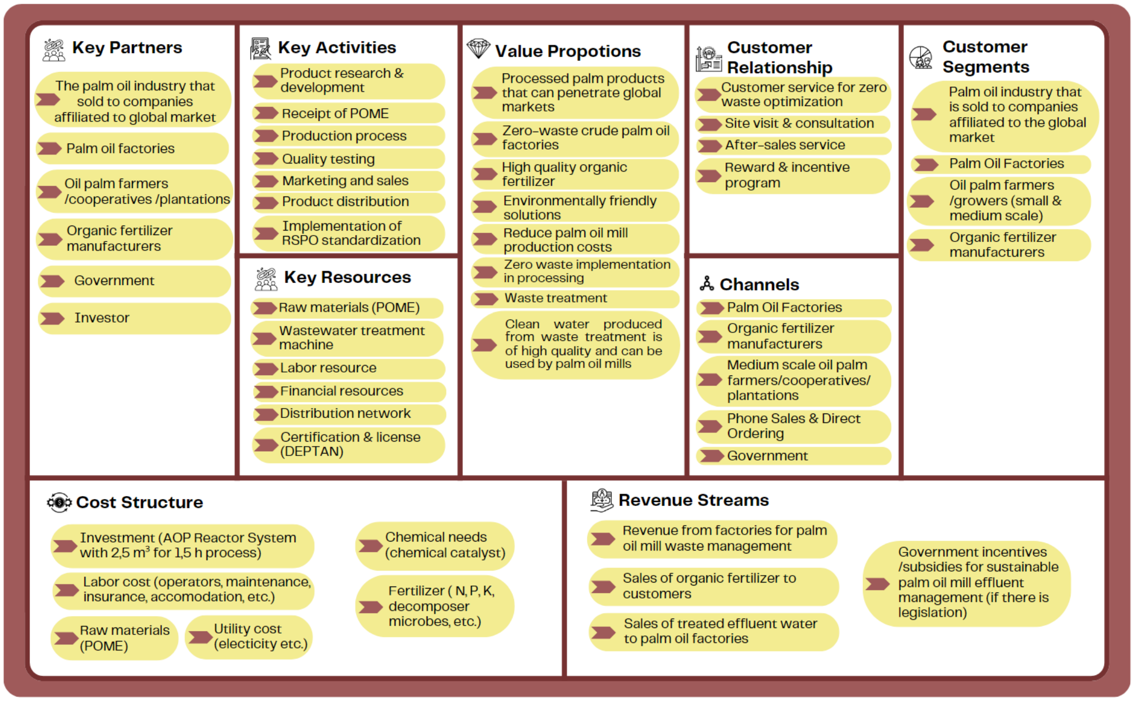

Figure 4. Business Model Canvas

4.2 Investment Feasibility Analysis

In the feasibility analysis of POME management, revenue is obtained from the cost of managing POME liquid waste, selling fertilizer from the remaining POME management, and reusing water from POME management. Meanwhile, the costs that must be incurred include the cost of purchasing and installing AOP machines, labor costs, utility costs, and the cost of fertilizer making materials. Details of these costs have been compiled in Table 1.

Table 1. Recapitulation of Income and Expenses

Revenue	Initial Investment	Year				
		1st	2nd	3rd	4th	5th
Waste processing take over costs		IDR1.427.040.000	IDR1.427.040.000	IDR1.427.040.000	IDR1.427.040.000	IDR1.427.040.000
Recycle water		IDR225.000.000	IDR225.000.000	IDR225.000.000	IDR225.000.000	IDR225.000.000
Fertilizer		IDR772.411.582	IDR772.411.582	IDR772.411.582	IDR772.411.582	IDR772.411.582
TOTAL Revenue		**IDR2.424.451.582**	**IDR2.424.451.582**	**IDR2.424.451.582**	**IDR2.424.451.582**	**IDR2.424.451.582**
Cost	**Initial Investment**	**Year**				
		1st	**2nd**	**3rd**	**4th**	**5th**
Purchase and installation of AOP reactor system (2,5 m³ for 1,5 h process)		IDR486.000.000	IDR486.000.000	IDR486.000.000	IDR486.000.000	IDR486.000.000
Raw materials (palm oil effluent)		IDR0	IDR0	IDR0	IDR0	IDR0
Labor (operators, maintenance, insurance, phone credit, accommodation, transportation)		IDR163.200.000	IDR179.520.000	IDR197.472.000	IDR217.219.200	IDR238.941.120
Utilities (electricity, water)		IDR240.000.000	IDR264.000.000	IDR290.400.000	IDR319.440.000	IDR351.384.000
Chemical needs (chemical catalyst)		IDR300.000.000	IDR300.000.000	IDR300.000.000	IDR300.000.000	IDR300.000.000
Fertilizer		IDR198.000.000	IDR198.000.000	IDR198.000.000	IDR198.000.000	IDR198.000.000
TOTAL Cost		IDR1.387.200.000	IDR1.427.520.000	IDR1.471.872.000	IDR1.520.659.200	IDR1.574.325.120
Net Cashflow	**-IDR1.387.200.000**	**IDR1.037.251.582**	**IDR996.931.582**	**IDR952.579.582**	**IDR903.792.382**	**IDR850.126.462**
Net Cashflow Cumulative	-IDR1.387.200.000	IDR1.037.251.582	IDR2.034.183.164	IDR2.986.762.745	IDR3.890.555.127	IDR4.740.681.589

The results of the calculation of net cashflow and cumulative net cashflow for 5 years are shown in the graph in Figure 5 below.

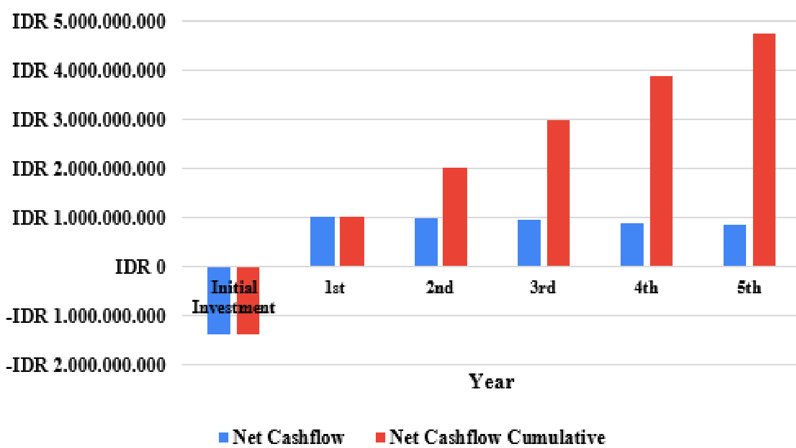

Figure 5. Cashflow POME Wastewater Treatment

Furthermore, the net present value calculation is carried out to determine the profit or loss obtained within a period of 5 years as shown in Table 2 below.

Table 2. Net Present Value

Year	Cashflow	Discount Rate	Present Value
Initial	-IDR1.387.200.000	1,00	-IDR1.387.200.000
1st	IDR1.037.251.582	0,909	IDR942.861.688
2nd	IDR996.931.582	0,826	IDR823.864.259
3rd	IDR952.579.582	0,751	IDR715.673.040
4th	IDR903.792.382	0,683	IDR617.290.197
5th	IDR850.126.462	0,621	IDR527.843.520
NPV			**IDR2.240.332.703**

The results of the NPV calculation show a positive value, which means that the investment is considered profitable because the present value of the incoming cash flow is greater than the initial cost of the investment.

4.2.1 Internal Rate of Returm (IRR)

The results of the previous NPV calculation are used to calculate the IRR. The IRR value for NPV 2, which is negative, reaches 66%, which is shown in Table 3 as follows.

Table 3. Calculation of IRR

Year	Cashflow	Discount Rate 1 (10%)	Present Value 1	Discount Rate 2 (66%)	Present Value 2
Initial	-IDR1.387.200.000	1,00	-IDR1.387.200.000	1,00	-IDR1.387.200.000
1st	IDR1.037.251.582	0,909	IDR942.861.688	0,870	IDR624.850.350
2nd	IDR996.931.582	0,826	IDR823.864.259	0,756	IDR361.783.852
3rd	IDR952.579.582	0,751	IDR715.673.040	0,658	IDR208.246.161
4th	IDR903.792.382	0,683	IDR617.290.197	0,572	IDR119.024.489
5th	IDR850.126.462	0,621	IDR527.843.520	0,497	IDR67.443.965
NPV			**IDR2.240.332.703**	**-IDR5.851.183**	

$$\text{IRR} = 10\% + (66\% - 10\%) \times \frac{\text{IDR2.240.332.703}}{(\text{IDR2.240.332.703} - (-\text{IDR5.851.183})}$$
$$= \mathbf{65,85}\%$$

The results of the IRR calculation show that it is feasible to invest because the IRR value exceeds the required rate of return of 10%.

4.2.2 Return of Investment (ROI)

The rate of return on investment (ROI) is commonly used as a tool to analyze the profitability of a company or project.

$$\text{ROI} = \frac{\text{IDR4.740.681.589}}{\text{IDR7.381.576.320}} \times 100\%$$
$$= \mathbf{64,22}\%$$

Based on the calculation of the ROI value, it shows that the POME handling business using AOP Nanobubble is said to be feasible and profitable because the ROI value is 64.22% and has a positive value.

4.2.3 Payback Period (PP)

The PP calculation in this study uses a preference time of two years. Based on the PP analysis in the POME treatment commercialization feasibility test using AOP Nanobubble, it is calculated using the following equation.

$$PP = 2 + \left(\frac{\text{IDR1.387.2000.000} - \text{IDR2.034.183.164}}{\text{IDR2.986.762.745} - \text{IDR2.034.183.164}}\right) \text{ x 1 tahun}$$
$$= \mathbf{1,32\ tahun \sim 1\ tahun\ 4\ bulan}$$

The PP calculation results show that the time required to return the initial investment value in the POME management business using AOP Nanobubble is 1 year and 4 months, which is less than the preference time determined by previous researchers. Therefore, we can conclude that the POME management business employing AOP Nanobubble is viable and carries a comparatively minimal business risk.

5. Conclusion

The waste products of the palm oil industry in Indonesia in the form of POME reach 50%, or around 2.5 to 3.37 tons per one ton of FFB, increasing the production of greenhouse gas emissions. In an effort to reduce these emissions, the government issued a policy MOA No. 38 of 2020 related to the ISPO (Indonesian Sustainable Palm Oil) standard. The Advanced Oxidation Process (AOP) Nanobubble method, which can oxidize various types of contaminants, is one of the alternatives for POME management. The feasibility analysis reveals that commercializing POME processing using AOP Nanobubble is viable, as evidenced by its NPV value of IDR 2,240,332,703, IRR of 65.85%, ROI of 64.22%, and payback period of 1 year and 4 months. Therefore, the palm oil industry can apply AOP Nanobubble technology to treat POME, anticipating a more efficient and eco-friendly wastewater treatment solution.

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