

Economic study of corn cob biomass as a boiler fuel substitution at PT XYZ in the animal feed industry

Muhammad Dafa Alisharsa ^{1*}, Wiwik Handayani ²

^{1,2,3} Universitas Pembangunan Nasional Veteran, Jawa Timur, Indonesia

Abstract

The use of biomass fuels such as palm kernel shells and candlenut shells has been implemented by the animal feed industry, but its energy consumption is still relatively high. This study aims to evaluate the feasibility of corn cobs as an alternative boiler fuel in reducing production costs. The method used is a quantitative descriptive approach with simulations through RETScreen software. The results show that the use of corn cobs combined with candlenut shells can produce energy savings, improve the economic value of the project NPV of 169,136 USD when converted to rupiah is obtained at Rp 2,748,460,000, IRR of 90,7%, payback period of 0.98 years (11 months), while the use of corn cobs combined with palm kernel shells produces NPV of 187,344 USD when converted to IDR is Rp 3,044,340,000, IRR of 105% and payback period of 1 year.

Keywords: Biomass, Production Process Efficiency, Green Manufacturing, RETScreen.

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*Correspondence author:

21012010009@student.upnjatim.ac.id

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INTRODUCTION

According to data from the Ministry of Energy and Mineral Resources, Indonesia's energy consumption in 2023 will still be dominated by fossil fuels, accounting for approximately 80% of the total energy mix, comprising 40.46% coal, 30.18% petroleum, and 16.28% natural gas. Meanwhile, the contribution of new and renewable energy (EBT) has only reached 13.09% of the total energy mix. A research article by Lahope (2024) states that, through the National Energy Policy (KEN), the Indonesian Government is targeting a 23% share of new and renewable energy by 2025. This target was set because Indonesia remains one of the largest consumers of fossil fuels in Southeast Asia, while renewable energy utilization remains relatively low. Improving the quality of life of the community needs to be supported by the development of renewable energy to reduce dependence on fossil fuels. Indonesia has various environmentally friendly alternative energy sources that are ready to be utilized, so that wider use of renewable energy is believed to contribute to improving community welfare (Bosman, 2024). According to Murwani Dewi Wijayanti, biomass development is currently geared toward reducing dependence on fossil fuels, as biomass is considered more environmentally friendly and can mitigate the negative impacts of agricultural waste that has not yet been fully addressed. Biomass use is far more environmentally friendly than fossil fuels, as each region and country has its own biomass and technology for processing biomass into renewable energy (Luthfi Parinduri, Taufik Parinduri, 2022).

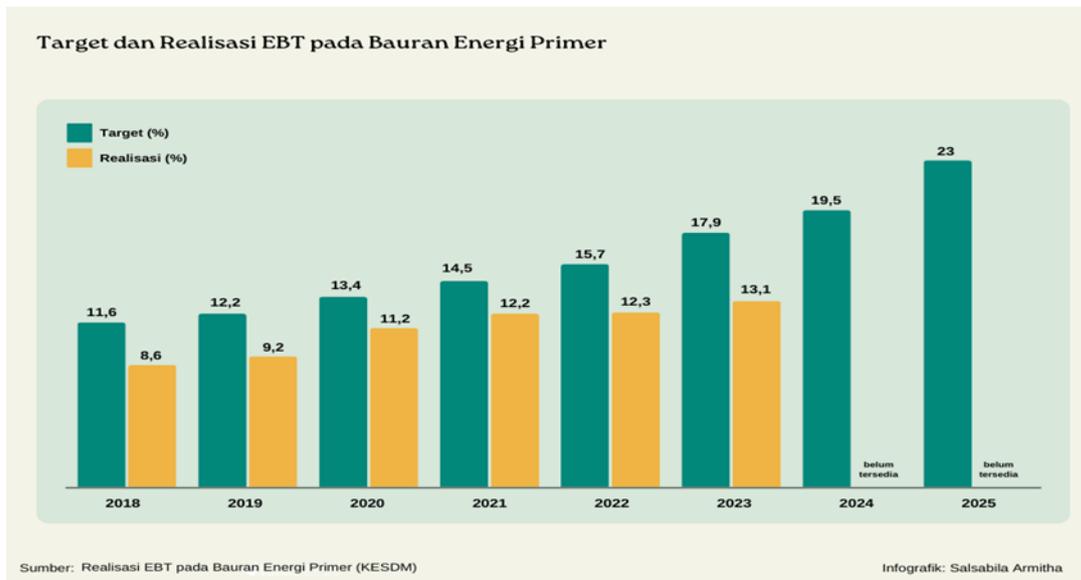


Figure 1. Renewable energy targets and realization
Source: KESDM 2025

The national renewable energy potential is enormous, encompassing 23.9 GW of geothermal energy, 207.8 GW of solar energy, and 32.6 GW of biomass. However, utilization remains low. As of 2023, renewable energy only accounts for around 13% of the energy mix, far below the 23% target for 2025. Key obstacles include limited infrastructure, suboptimal regulations, and minimal investment. However, projects such as the 145 MW Cirata Floating Solar Power Plant and the utilization of biomass from palm oil waste have shown positive progress. The government is targeting renewable energy to reach 31% by 2030 and net-zero emissions by 2060, with priorities on bioenergy, solar energy, and green hydrogen. The use of renewable energy has become a significant focus in the industrial sector, including the animal feed industry, to reduce dependence on fossil fuels and reduce production costs. One widely used alternative energy source is biomass, such as palm kernel shells and candlenuts, which are considered more environmentally friendly and affordable. In Indonesia, many companies have begun integrating biomass as a primary energy source in boiler operations. One such company

is PT XYZ, which has implemented palm kernel shell and candlenut-based biomass in its animal feed production system.

PT XYZ Tbk produces various types of animal feed, including feed for broilers, layers, broilers, concentrates, quail feed, and other feeds. The company also produces day-old chicks, live chickens ready for slaughter, broiler chickens, and various processed food products. PT XYZ Tbk is committed to providing quality products to the public by implementing strict biosecurity technology to ensure product cleanliness and hygiene.

Table 1. Use of Candlenut Shells

Year	Use of Candlenut Shells / Kilogram Unit
2022	547.741
2023	948.531
2024	324.908

Source: PT XYZ Company Documents

Table 2. Palm Kernel Shell Usage

Year	Palm Kernel Shell Usage / Kilogram Unit
2022	3.008.760
2023	2.853.956
2024	2.035.124

Source: PT XYZ Company Documents

PT XYZ Tbk. operates a biomass-fueled boiler using palm kernel shells and candlenut shells as a coal substitute to reduce energy costs. The company targets an energy efficiency of 12 kg per metric ton of animal feed through the use of a mixture of palm kernel shells and candlenut shells at a price of around Rp1,400/kg. This target was previously achievable when feed production was at high capacity. However, under current suboptimal production conditions, energy consumption has increased to 14 kg per metric ton, thereby reducing cost efficiency. Therefore, the company is seeking alternative fuel substitutes that are more economical, have equivalent or higher calorific value, and have adequate supply to support factory operations.

The main problem addressed in this study is how to assess the technical and economic feasibility of using corn cobs as a biomass fuel substitute in boiler engines, as well as its impact on energy efficiency and reducing the cost of animal feed. Corn cobs, the lower part of the stem remaining after harvest, are often considered a valueless agricultural waste. However, corn cobs are chosen as a substitute fuel for biomass boilers due to their high calorific value ($\pm 5,800\text{--}9,400$ cal/g) and low ash content ($\pm 3\text{--}8\%$), making them efficient for combustion (Pangga et al., 2021). Compared to other biomass such as rice husks (3,000–4,200 cal/g; priced at IDR 400–700/kg), palm kernel shells (4,000–5,000 cal/g; IDR 800–1,400/kg), and coconut shells (6,000–7,000 cal/g; IDR 1,500–2,000/kg), corn cobs offer a relatively competitive price, ranging from IDR 2,500–6,000/kg, and have physical characteristics suitable for use in industrial boilers (Adoe et al., 2022). Their utilization also supports operational cost efficiency and aligns with the implementation of green manufacturing principles. The potential for corn cobs in Indonesia is quite high, one of which is the processing of corn cobs into briquettes that can be used as solid biomass fuel and have a fairly high selling value in both local and international markets (Aryza et al., 2024). The gap found from previous research is the absence of a comprehensive study that specifically analyzes the use of corn cobs with an energy software-based simulation approach such as RETScreen, especially in the context of the animal feed industry in Indonesia.

This research is based on the use of energy simulation methods using RETScreen software to compare scenarios of biomass fuel combinations: palm kernel shells, candlenut shells, and corn cobs. Thus, this study not only assesses financial and technical aspects, but also integrates environmental analysis and seasonal efficiency as a basis for managerial decision-making. RETScreen Expert is a clean energy management software designed to help energy

professionals and decision-makers identify, assess, and optimize the technical and financial feasibility of clean energy projects. This platform enables feasibility, performance, and portfolio analysis of various facilities, while supporting monitoring, verification, and management of actual performance to identify opportunities for energy savings or increased energy output.

The purpose of this study is to analyze the feasibility of using corn cobs as an alternative fuel in PT XYZ's boiler engine, through an evaluation of technical, financial, and environmental aspects using RETScreen software simulation as the main tool.

RESEARCH METHOD

This research uses a quantitative descriptive approach, which is a type of research that utilizes quantitative data and is analyzed descriptively to understand the information academically. Data, especially numerical data, are collected through questionnaires, questionnaires, or field observations, then presented in the form of tables, graphs, curves, histograms, stem-and-leaf, and statistical measures such as mean and median (Andy Alfatih, 2024). The study aims to analyze the technical, economic, and environmental feasibility of using alternative biomass fuels (corn cobs). The data used are secondary data from PT XYZ, including fuel consumption, boiler efficiency, energy requirements, and estimated costs and emissions.

This study did not include direct testing of animal feed productivity due to the company's operational limitations. Implementing new fuels at maximum production capacity could potentially impact the stability of the production process and animal feed quality. Therefore, the evaluation focused on technical and economic aspects based on energy simulations.

The fuel properties assumptions used in the RETScreen simulation refer to the default parameters available in the software, which are compiled based on technical databases and renewable energy literature. These values include the calorific value and fuel rate of each biomass type. The selection of these parameters has been adjusted to the biomass characteristics described in the introduction, so no additional laboratory testing was conducted in this study. In this case, the calorific value of candlenut shells or almond shells is 20.3 MJ/kg, the calorific value of palm shells is 23.1 MJ/kg, and the calorific value of corn cobs is 18.9 MJ/kg.

The calibration step in this study was carried out internally by adjusting the input parameters in the RETScreen software to represent the company's actual operational conditions during the one-month observation period. The initial conditions (baseline) were determined based on actual biomass consumption of 14 kg per metric ton of animal feed, with a fuel type of a mixture of palm kernel shells and candlenut shells, and a biomass price of Rp1,400 per kilogram. The technical parameters of the boiler used in the simulation included a boiler capacity of 6 tons, 24-hour operation time per day, and a boiler efficiency value of 80% under optimum conditions obtained from technical data on boiler types available on the market and literature references. Next, the biomass calorific value and system efficiency parameters were adjusted in RETScreen until the output results in the form of energy consumption and operational costs approached the company's actual data. Validation was carried out using software-based economic feasibility without conducting productivity trials. This was intended as a reference for managerial decisions in the use of corn cobs as a substitute material for boiler engines.

The analysis was conducted using RETScreen Expert software, a clean energy simulation software developed by Natural Resources Canada. RETScreen was used to simulate two main scenarios: (1) a reference scenario using a combination of palm kernel shells and candlenuts; and (2) a proposed scenario with partial or full substitution by corn cobs. Evaluation was conducted on several feasibility indicators, namely Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, Levelized Cost of Energy (LCOE), Benefit-Cost Ratio, and Cash Flow Analysis. In addition, the evaluation was supported by a business feasibility study to review several aspects aimed at determining whether the use of corn cobs is feasible or not. Here are some definitions of variables:

1. Green Manufacture

Green manufacturing is an approach to the production process designed to minimize negative impacts on the environment, conserve energy and natural resources, and maintain economic viability (Mukherjee, 2024). This concept encompasses the 6R principles (Reduce, Reuse, Recycle, Recover, Remanufacture, and Redesign), as well as the application of renewable energy and the use of environmentally friendly raw materials. Furthermore, green manufacturing emphasizes reducing waste and production residues to prevent environmental pollution, and encourages the reuse of reusable materials (Soesilo et al., 2024). The implementation of green manufacturing not only impacts environmental sustainability but also provides a competitive advantage for companies. By reducing waste in the production process, companies can increase efficiency and create added value in products (Sigit & Aryanto, 2025). Furthermore, the integration of technology into environmentally friendly production processes reinforces the primary goals of green manufacturing: efficient resource use and minimizing industrial waste (Asrul Fole et al., 2025).

2. Biomass

Biomass is the biodegradable portion of products, waste, and residues derived from biological sources such as agriculture, forestry, fisheries, and related industries. Biomass includes crop waste, animal waste, algae, and food and forestry residues that can be converted into bioenergy, biofuels, biochemicals, and bioproducts through biochemical or thermochemical processes (Samer, 2022). As a renewable resource, biomass supports the transition to a circular economy and reduces dependence on fossil fuels and environmental emissions. In Indonesia, biomass potential is enormous due to the abundance of agricultural and plantation waste such as oil palm, rice, and corn. Proper utilization of biomass can reduce greenhouse gas emissions, reduce air pollution, and support sustainable economic development (Aisyah, 2023). In Indonesia, various types of biomass, such as palm kernel shells, rice husks, and corn cobs, have been widely utilized as alternative fuels in industry, power plants, and boiler systems. As an energy source derived from plant and animal materials, biomass can be processed into biofuels and bioenergy, thus contributing significantly to the provision of renewable and sustainable energy at the national level (Rizki & Fithriana, 2024).

3. RETScreen

RETScreen is a renewable energy and energy efficiency feasibility analysis software developed by Natural Resources Canada. This software is designed to help users—from researchers to companies to governments—quickly and accurately evaluate clean energy projects technically, financially, and environmentally.

4. Business Feasibility Study

Dr. I Made Adnyana, S.E., M.M. explained that a business feasibility study is a process of assessing a business before it is implemented, which aims to minimize potential risks and uncertainties in the future. A business feasibility study is a systematic analytical process to assess the potential success of a business before it is launched, with the goal of minimizing risks and ensuring economic and non-economic benefits (Sutandi et al., 2024). This study covers legal, market, technical, financial, management, socio-economic, and environmental aspects, and involves data collection, analysis, and decision-making. This study enables business actors to make rational and strategic decisions, supporting planning, as well as business monitoring and control (Arifuddin et al., 2020).

Data triangulation in this study was applied to increase the validity of the economic feasibility analysis through cross-verification between sources, methods, and technical references. The primary data were obtained from PT XYZ Tbk.'s operational records during a one-month observation period, including actual biomass consumption of 14 kg per metric ton of animal feed, the type of fuel used (a mixture of palm kernel shells and candlenut shells), and the biomass price of Rp1,400 per kilogram. These data were verified by research conducted by Adoe et al. 2022 by comparing other biomass such as rice husks (3,000–4,200 cal/g; price Rp 400–

700/kg), palm kernel shells (4,000–5,000 cal/g; Rp 800–1,400/kg), and coconut shells (6,000–7,000 cal/g; Rp 1,500–2,000/kg), corn cobs offer a relatively competitive price, ranging from Rp 2,500–6,000/kg, and have physical characteristics suitable for use in industrial boilers. Validation was also carried out through confirmation with internal company parties, namely the Head of HSE and the Head of the Boiler Control Room, to ensure compliance between operational data, technical documents, and actual field conditions. All verified data was then analyzed using RETScreen software as the primary method for evaluating the economic feasibility of fuel substitution, without involving direct production trials.

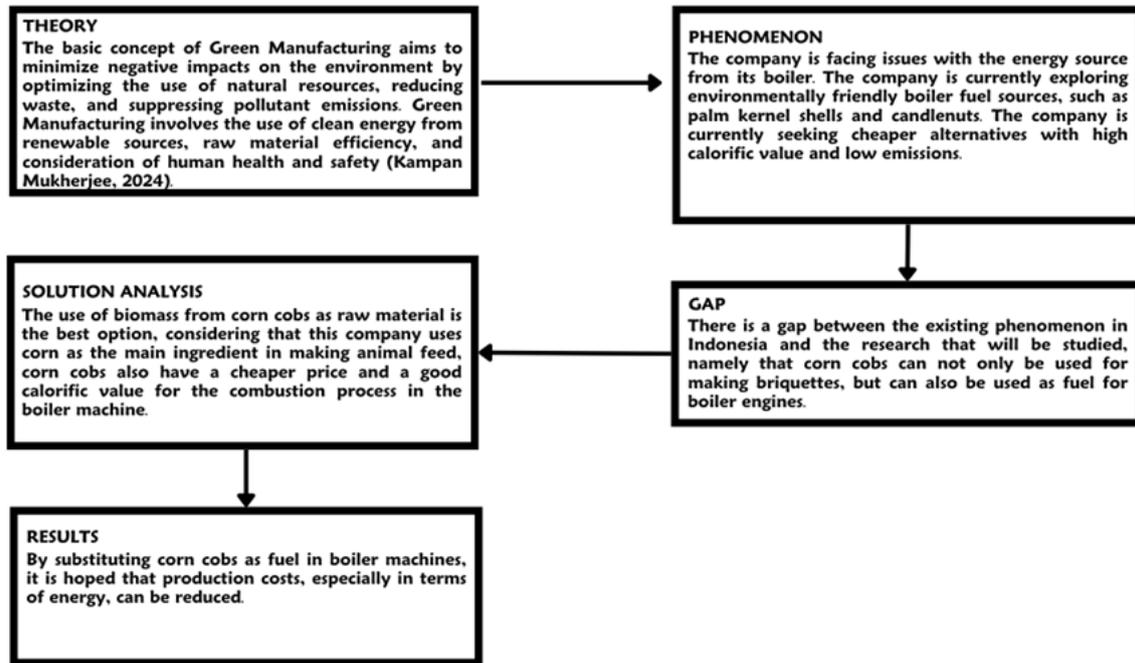


Figure 2. Conceptual Framework

RESULTS AND DISCUSSION

Result

PT XYZ is an integrated agribusiness company engaged in the poultry industry, from animal feed production, day-old chick breeding, broiler farming, to processing chicken meat into ready-to-consume processed products.

Data collection was conducted through direct observation to obtain information regarding boiler fuel usage at PT XYZ. This information included annual data on palm kernel shell and candlenut consumption. Subsequent data collection involved direct interviews with several relevant division heads, including the Head of HSE and the Head of the Boiler Control Room. After collecting data from company documents and references from scientific articles, a RETScreen software analysis was conducted to determine the economic impact of using corn cobs as a boiler fuel substitute on production costs. Following the software analysis, a business feasibility study was conducted to identify the feasibility of the project:

Table 3. Parameters of Biomass

Parameter	Value	Unit
Calorific Value of Palm Kernel Shells	23,1	Mj/Kg
Calorific Value of Candlenut Shells	20,3	Mj/Kg
Calorific Value of Corn Cobs	18,9	Mj/Kg
Combined Price of Palm Kernel Shells + Candlenuts (Company Reference)	1400	Rupiah
Price of Corn Cobs	1000	Rupiah

Sources : Company Documents and RETScreen Software

Table 4. Data Analysis Parameters from Biomass

Fuel	Seasonal Efficiency	Vapor Pressure	Superheated Temperature	Additional Water Temperature
Palm Kernel Shells	82%	8-12 bar	200°C	30°C
Candlenut Shells	80%	8-12 bar	200°C	30°C
Corn Cobs	75%	8-12 bar	200°C	30°C

Source: Company Document Sources and Article References

The following is an economic analysis using RetScreen software.

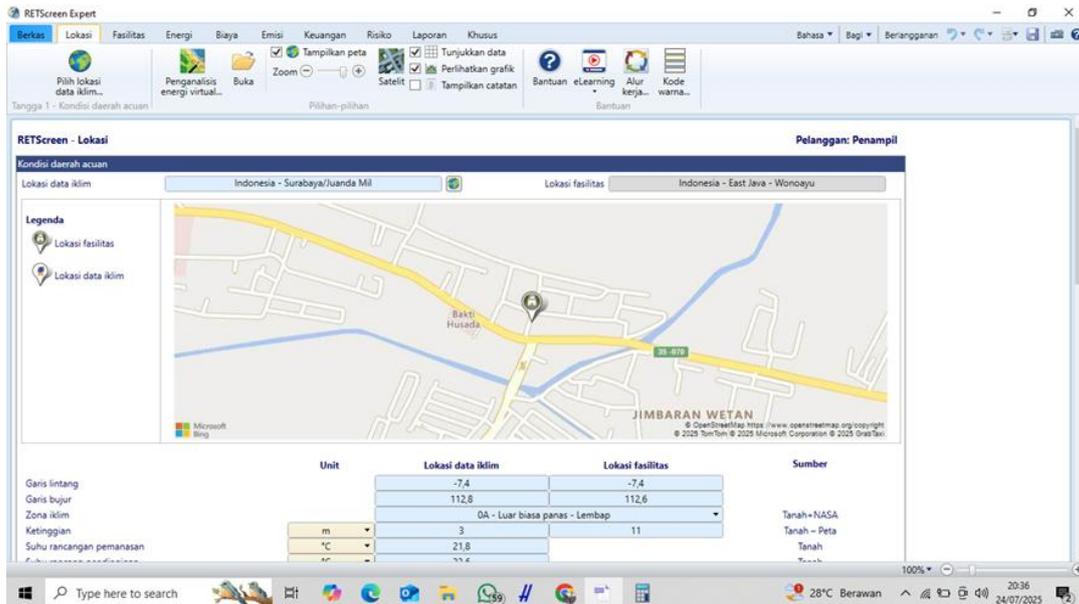


Figure 2. Location Selection Display in RETScreen Software

The first step is selecting the location where the project will be implemented. RETScreen has data synchronization with NASA to analyze the climate and weather in the project location.

1. Palm Kernel Shell + Corn Cob Scenario

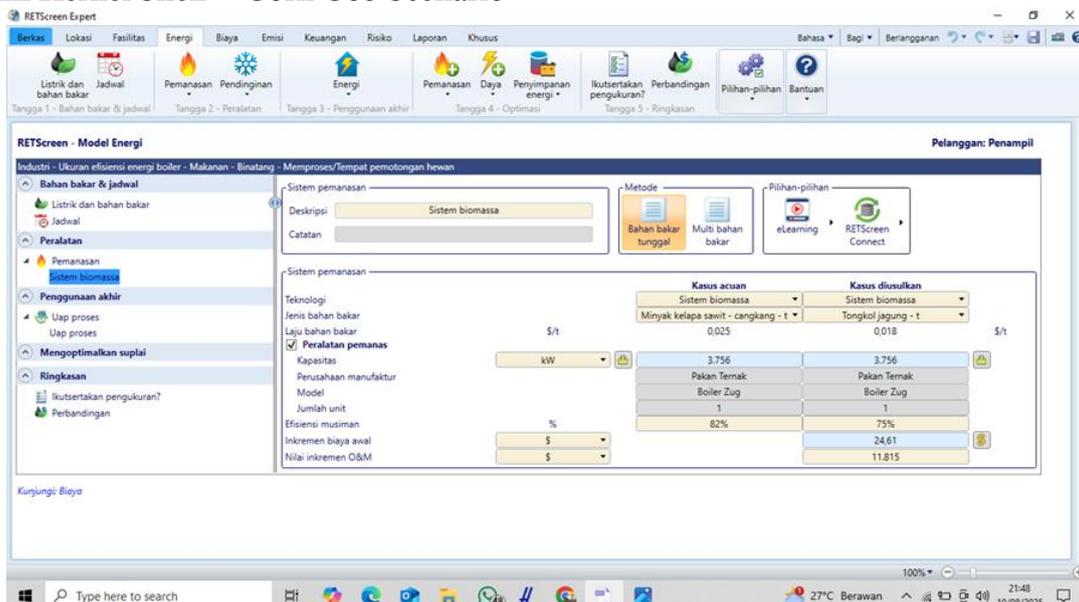


Figure 3. Energy Selection Display in RETScreen Software

The second stage is to input the first reference data, namely using palm shells and benchmarking with corn cobs, at this stage the researcher enters the fuel rate of each fuel based on the reference journal and inputs the annual electricity tariff based on company data, the rest of RETScreen will analyze starting from the calorific value, fuel rate per unit.

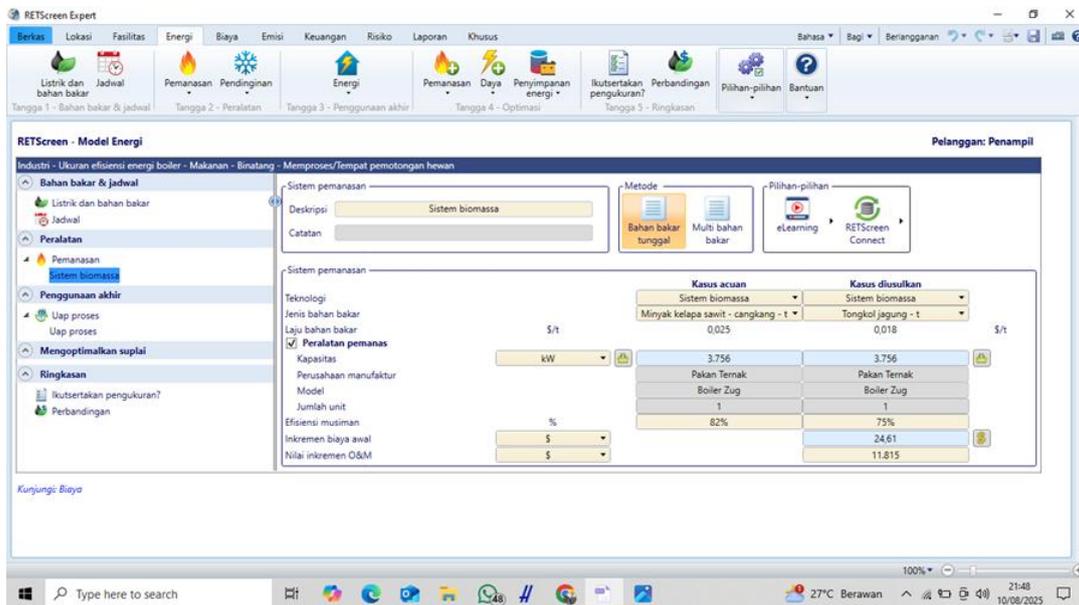


Figure 4. Display of Heating System Selection in RETScreen Software

In the third stage, the researcher began inputting the reference case of palm kernel shells and the proposed case of corn cobs. They then inputted seasonal efficiency for palm kernel shells of 82% and corn cobs of 75%, based on reference journals. Because the company plans to replace or substitute more cost-efficient biomass fuels, in this case corn cobs, the initial increment and operational and management increment costs will be calculated using the following formula:

- Initial Increment = Reference fuel price (1,400,000/ton) - Proposed fuel price (1,000,000/ton) / IDR 16,250 (USD) BCA Bank Exchange Rate (August 10, 2025) per unit in RETScreen
- Operational and Management Increment = Operational cost increment = Difference between reference fuel price per kilogram (IDR 1,400 per palm kernel shell) - Proposed fuel price (IDR 1,000 per corn cob) = IDR 400 * Production Capacity (40,000 tons per month x 12 = 480,000 tons per year) / Rp. 16,250 (usd) (currency unit from RETScreen).

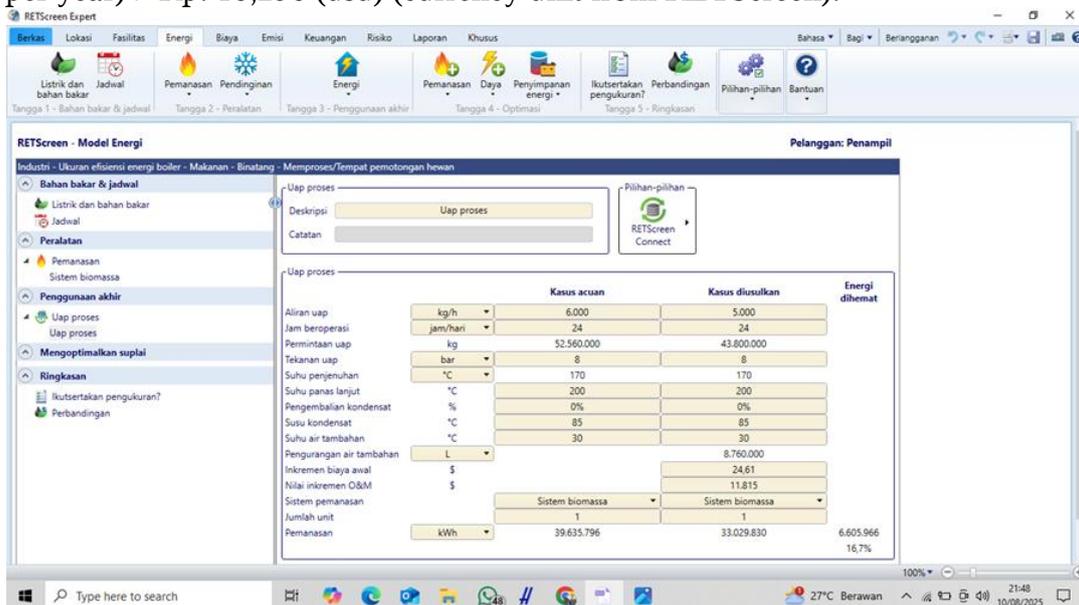


Figure 5. Output Display of the Biomass System in RETScreen Software

From this stage, it is analyzed that the savings that occur in the proposed case by reducing the water vapor to 5000 kg/h from the maximum limit of 6000 kg/h can result in heating savings in kWh of 16.7%

Table 5 . Measurement Model Evaluation Results

Indicator	Criteria	Result	Conclusion
Loading Factor	> 0.70	All indicators > 0.70	Convergent validity achieved
Average Variance Extracted (AVE)	> 0.50	All constructs > 0.50	Convergent validity achieved
Composite Reliability (CR)	> 0.70	All constructs > 0.70	Good internal consistency
Cronbach's Alpha	> 0.70	All constructs > 0.70	Good internal consistency
Variance Inflation Factor (VIF)	< 5	All indicators < 5	No multicollinearity issues

Source : Results of research data processing, 2025

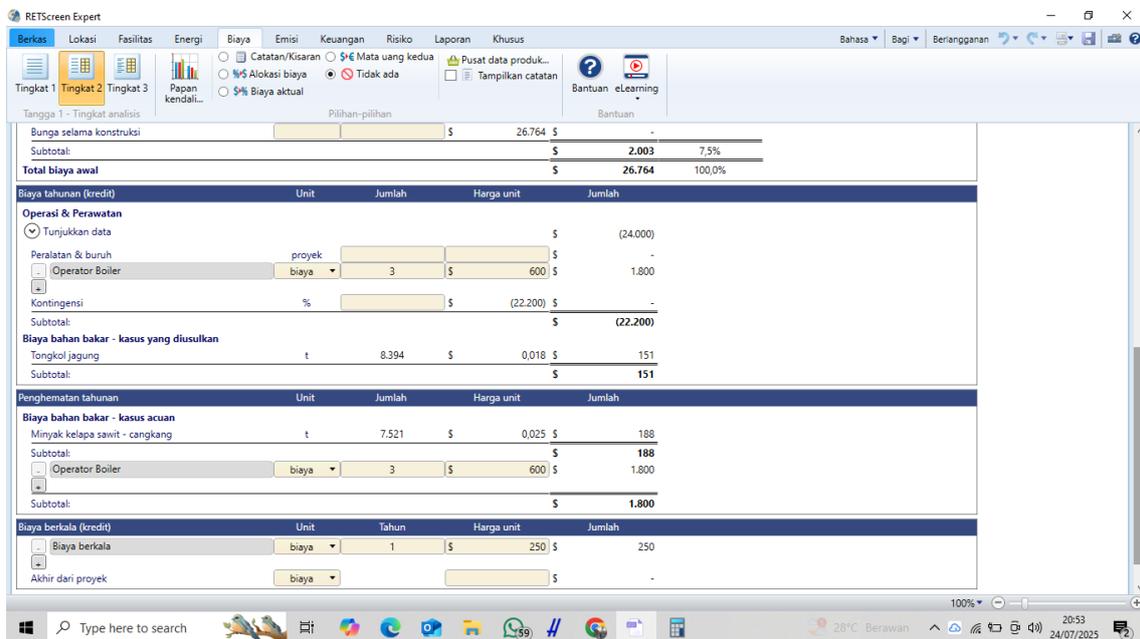


Figure 6. Display of Operational Cost Analysis in RETScreen Software

The next step is to input a cost analysis to calculate how much the company's initial investment is to replace biomass fuel from palm kernel shells to corn cobs, starting from a feasibility study, construction or purchase of a boiler machine for around 250 million and technical installation for around 30 million for installation and adjustment of the boiler to the location and fuel used. Then input spare parts data amounting to 2% of the total boiler purchase price, then input the cost of the boiler machine operator, there are 3 people who maintain the boiler for 3 shifts and are given a wage of approximately 600 USD. This is also calculated when there is a long shift (overtime several times a month).

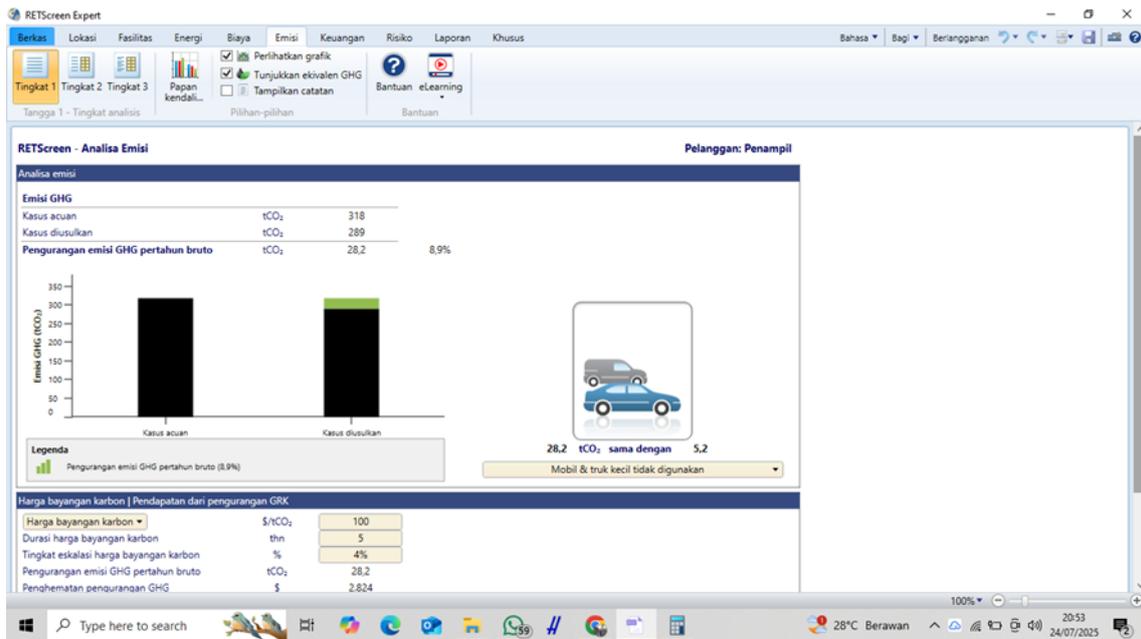


Figure 7. Emission Analysis Display in RETScreen Software

The next step is to analyze the emissions generated if the company switches from palm kernel shells to corn cobs entirely. The graph above shows an 8.9% reduction in emissions, equivalent to five cars or small trucks. This is quite good, in line with the government's target of net zero by 2050. The input for the shadow carbon price, the duration of the shadow carbon price, and the rate of escalation of the shadow carbon price are based on references from the World Bank Document journal.

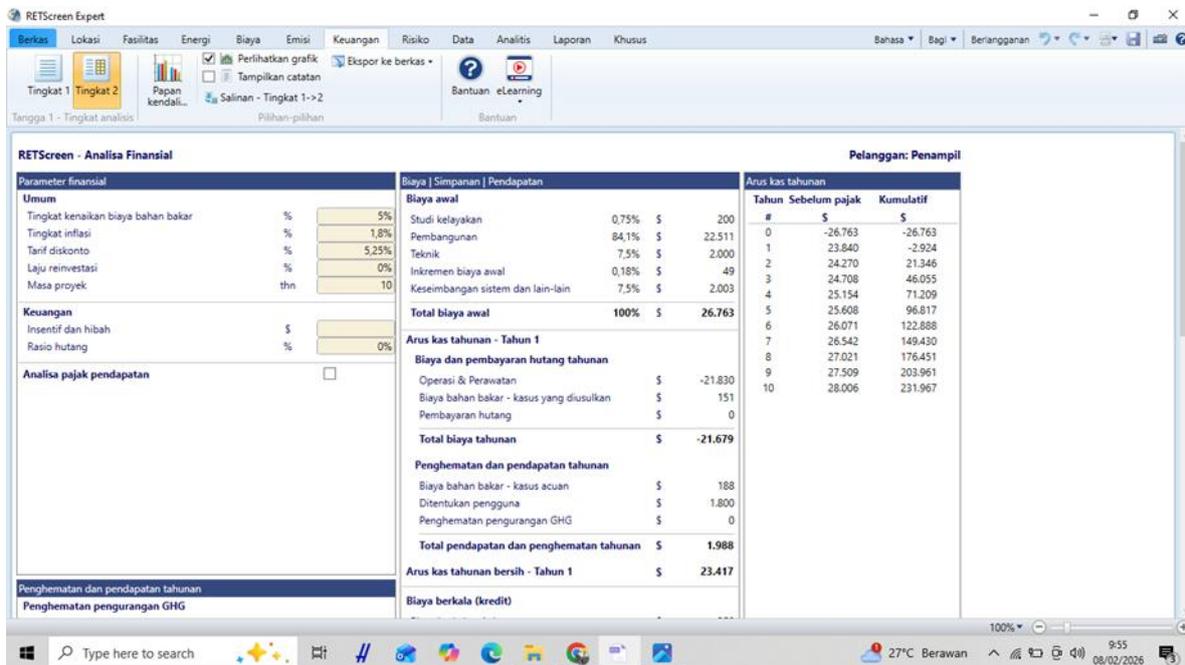


Figure 8. Financial Analysis in RETScreen Software

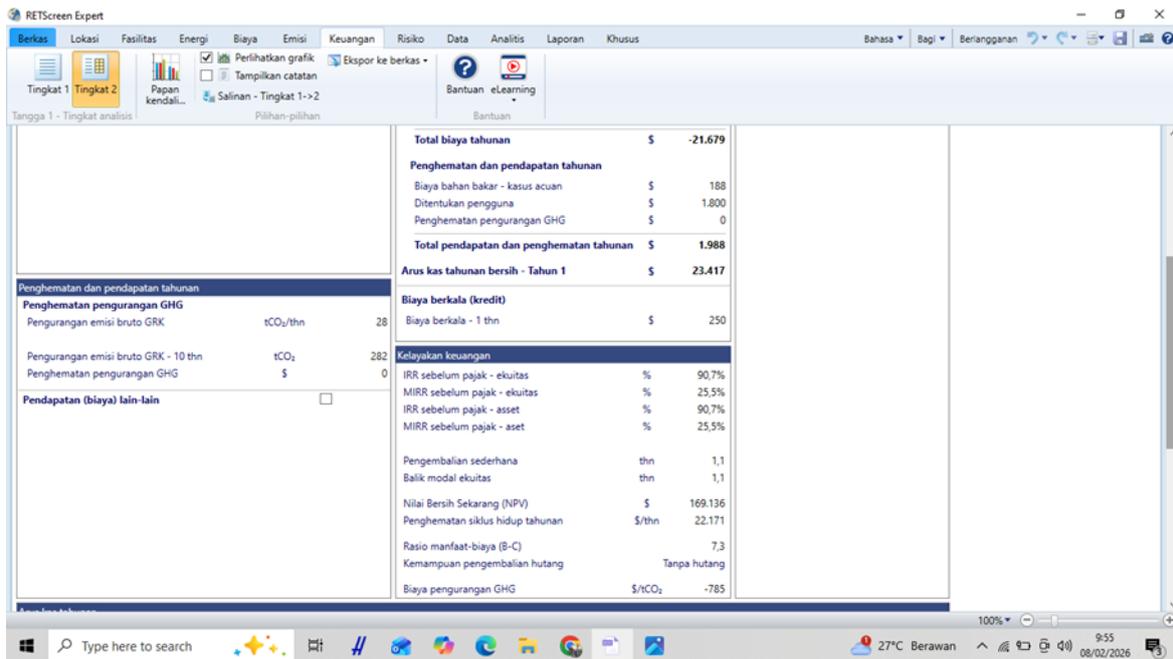


Figure 9. Display of Financial Analysis of NPV, IRR, Payback Period, Cost Benefit Ratio in RETScreen Software

The next analysis is the financial aspect of cash flow from the first year to the 10th, in the first year there was a minus value because there was an initial investment of 26,763 USD or around Rp. 434,898,750 based on the BCA Bank exchange rate on August 10, 2025 (Rp. 16,250) for the boiler machine procurement process, purchasing raw materials, and training boiler operators, at this stage also analyzes the financial feasibility starting from the IRR before tax, Payback period is approximately 1 year if consistently using corn cobs which is analyzed by this researcher in the most optimum conditions, at this stage also calculates the Net Present Value of 169,136 USD if converted into IDR with the exchange rate (Rp. 16,250) based on the BCA Bank reference on Sunday, August 10, 2025, the conversion result is Rp. 2,748,460,000 and annual cycle savings of 22,171 USD or equivalent to Rp. 360,278,750, the last analysis is Cost The Benefit Ratio has a value of 7.3, which is positive for implementation, and the emission reduction cost is -785. The following is a cumulative cash flow analysis graph.

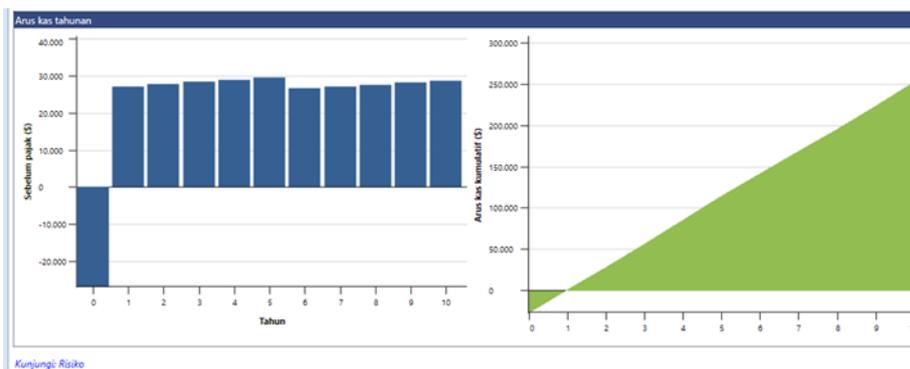


Figure 10. Cumulative Cash Flow Graph Display in RETScreen Software

2. Candlenut Shell + Corn Cob Scenario

At this stage, the scenario for completely replacing candlenut shells with corn cobs has the same flow as the initial scenario, starting with inputting project location data into the RETScreen software and then starting the analysis, which begins as follows:

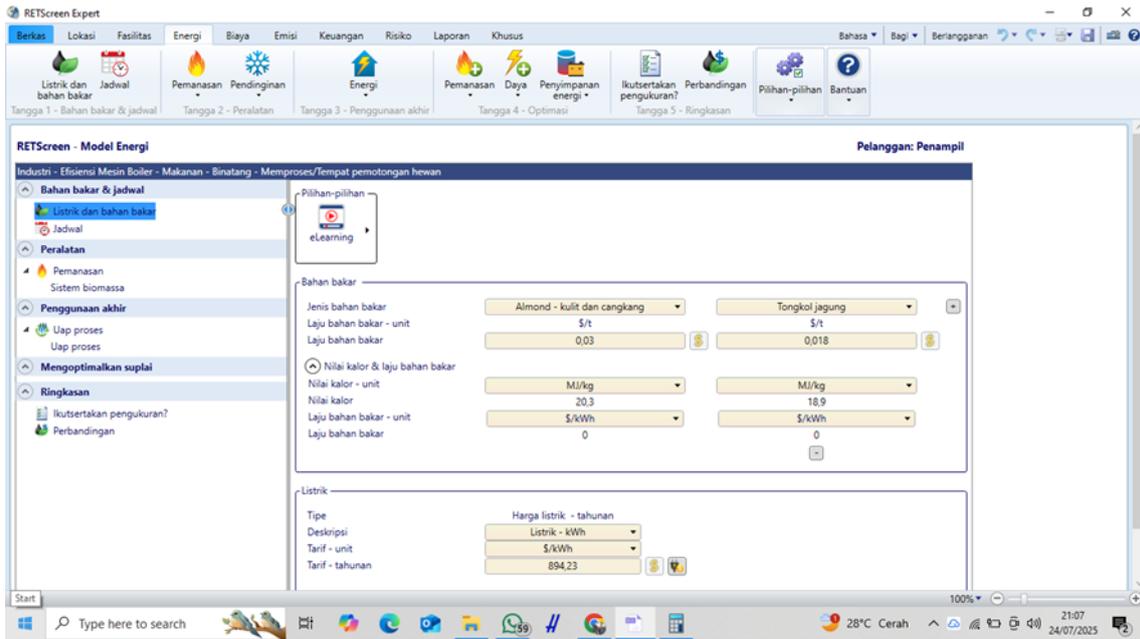


Figure 11. Energy Selection Display in RETScreen Software

At this stage, RETScreen does not have candlenut shell biomass, but is replaced with almond shells which have a calorific value and fuel rate that is more or less the same as candlenut shells, with a calorific value of 20.3 Mj/kg which is quite large compared to corn cobs which have a calorific value of 18.9 Mj/kg.

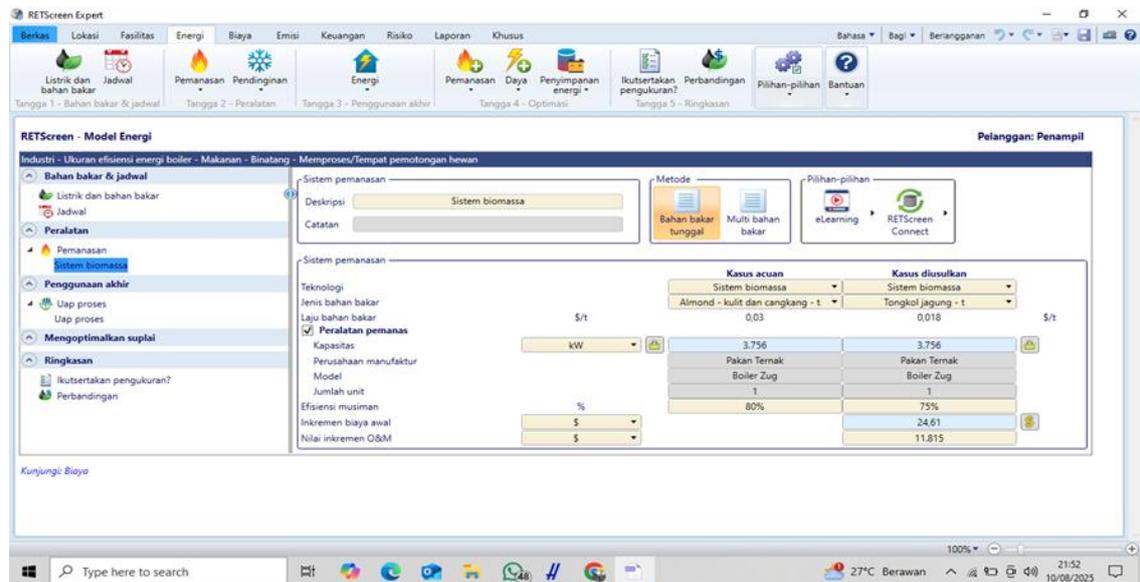


Figure 12. Display of Heating System Selection in RETScreen Software

This analysis selected a biomass system with a seasonal efficiency of 80% and a corn cob of 75%, which is larger than that of corn cobs and corresponds to a higher calorific value than corn cobs. The remaining variables were adjusted using RETScreen software.

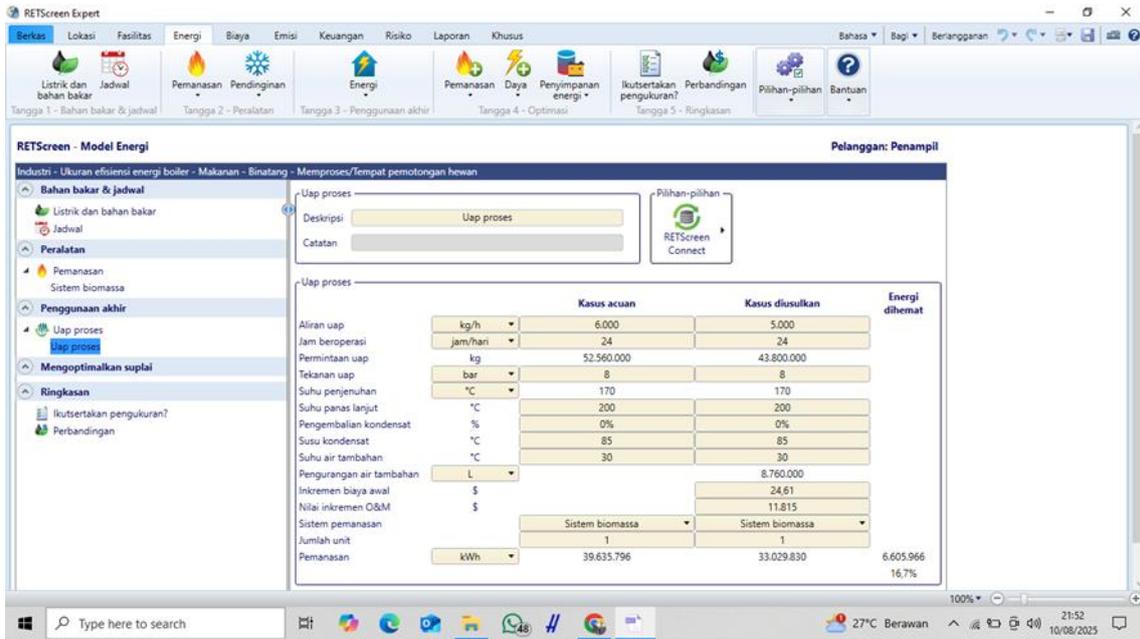


Figure 13. Output Display of the Biomass System in RETScreen Software

This analysis, similar to the previous one, involves inputting all the requirements from the RETScreen software. Several variables are already provided, making the analysis easier. The analysis shows the same savings as palm kernel shells if replaced with corn cobs by simply reducing the steam flow to 5,000 kg/h from its maximum capacity.

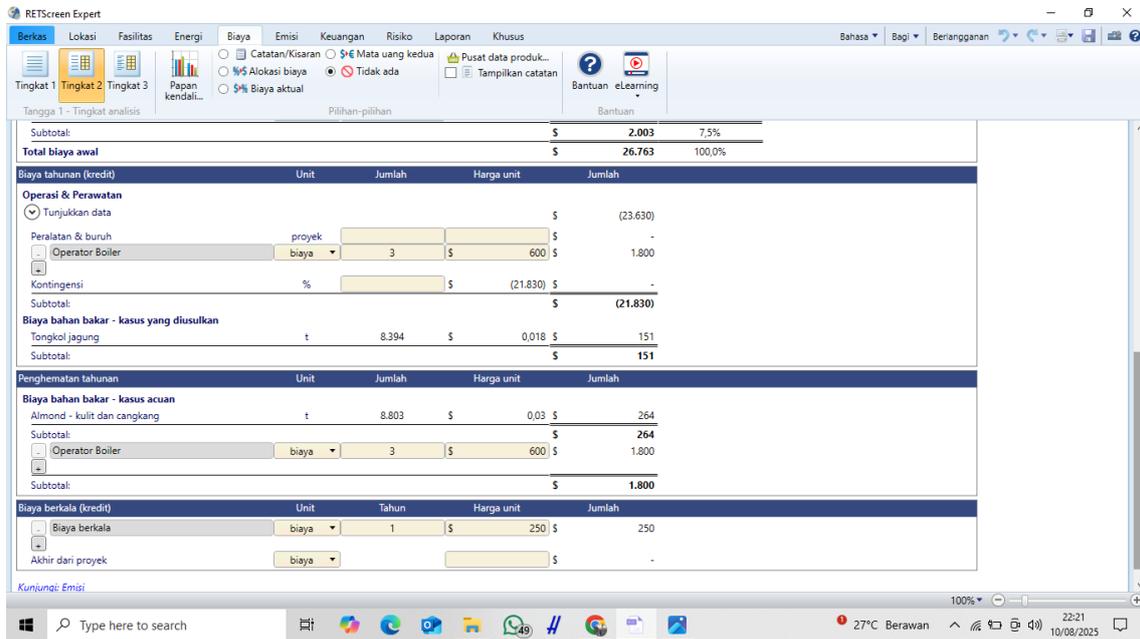


Figure 14. Display of Initial Investment Cost Analysis in RETScreen Software

At this stage, it is not much different from the previous one, namely conducting an analysis related to the costs incurred by the company to replace its biomass fuel with corn cobs.

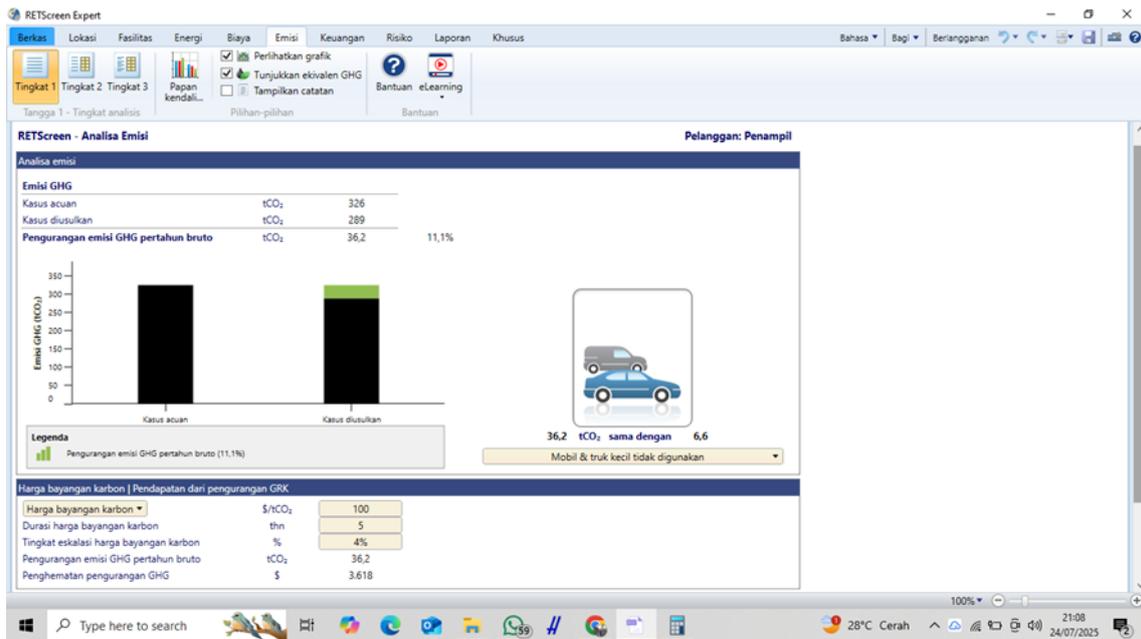


Figure 16. Emission Analysis Display in RETScreen Software

The next stage is to analyze the emissions produced when moving from candlenut or almond shells can reduce emissions by 11.1% or the same as 6 - 7 cars or small trucks operating on the road, this can increase the possibility of improving air quality especially in industrial areas that are known for poor air quality.

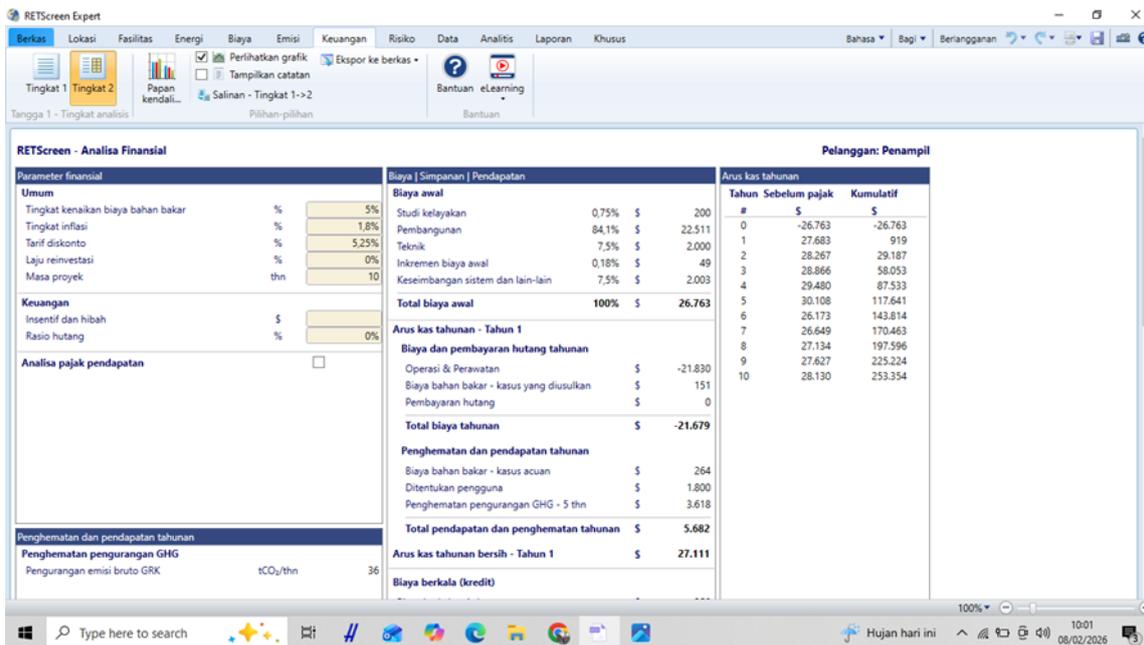


Figure 17. Financial Analysis in RETScreen Software

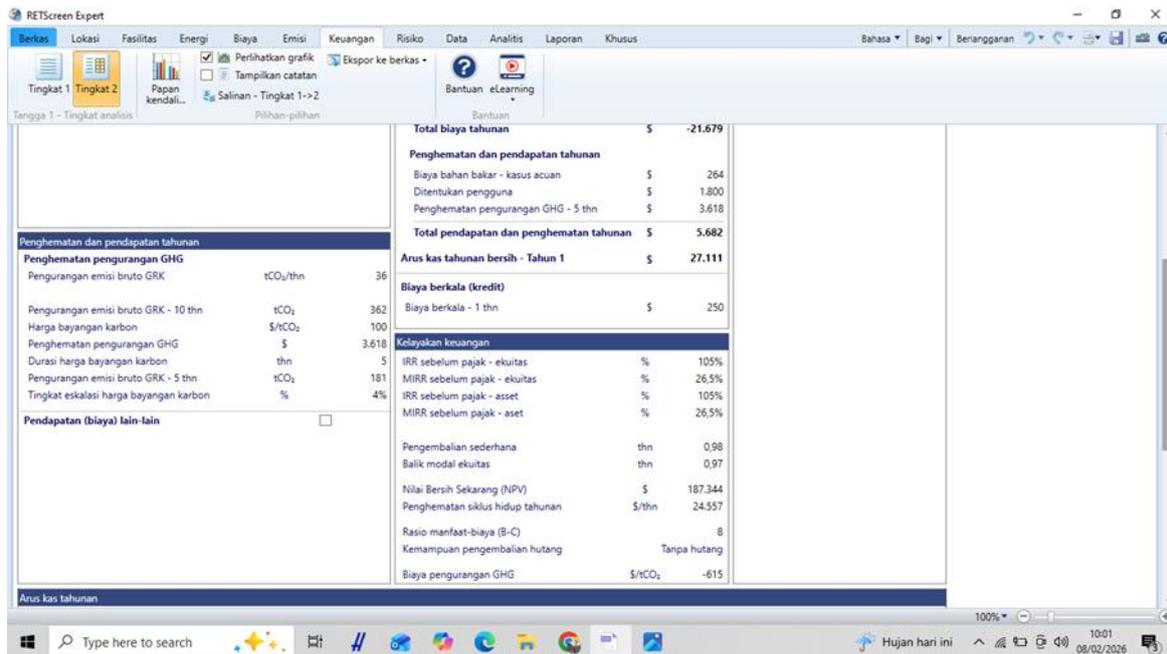


Figure 18. Display of Financial Analysis of NPV, IRR, Payback Period, Cost Benefit Ratio in RETScreen Software.

In the next analysis stage, namely analyzing finances, starting with general financial parameters that look for references from government websites to further maximize the calculation of the analysis. This stage analyzes initial cost expenditures, and includes initial costs, IRR 105%, Payback Period ±0.98 years (9–10 months), NPV analysis of 187,344 USD if converted to rupiah, it is obtained at IDR 3,044,340,000 with annual savings of 24,557 USD with a conversion value to rupiah, a value of IDR 399,051,250 is obtained and a Cost Benefit Ratio of 8 (declared feasible) and closed with an emission reduction cost of -615.

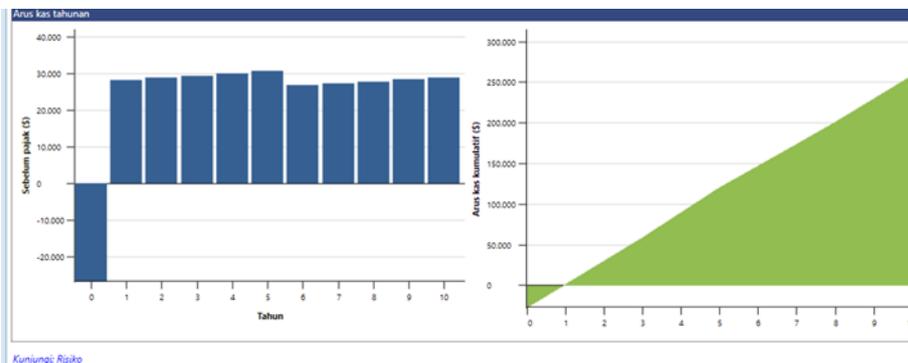


Figure 19. Cumulative Cash Flow Graph Display in RETScreen Software

Discussion

If a company substitutes with certain biomass, it is possible that it will achieve optimal efficiency, lower costs and can anticipate if at some point some of the biomass fuels experience product shortages, with the following proportions:

Table 6. Comparison if Corn Cob Biomass is Substituted

Indicators	Palm Kernel Shells 50% + Corn Cobs 50%	Candlenut or Almond Shells 50% + Corn Cobs 50%	Palm Kernel Shells 60% + Candlenut or Almond Shells 20% + Corn Cobs 20%
Price	1400 + 1000 = 2400 / 2 = 1.200	1400 + 1000 = 2400 / 2 = 1.200	840 + 280 + 200 = 1.320

Calorific Value	15,5 - 16 Mj/Kg	15 - 16 Mj/Kg	15 - 16 Mj/Kg
Final Remarks	Efficient, corn cobs are substituted at 50% due to the higher calorific value of palm kernel shells than corn cobs. Furthermore, the company is more economical if the boiler uses 100% palm kernel shells as fuel, at a price of 1,400 kg.	Efficient, and financially superior, with the price per kilo of corn cobs and candlenuts being the same as using palm kernel shells and corn cobs.	Quite efficient because it is close to the benchmark case, with the initial price per kilo of palm kernel shells and candlenuts being 1,400 rupiah per kilogram. In this case, it is intended only for emergencies in the event of a shortage of one of the biomass fuels

According to the book written by H. Sri Sutandi, et al., 2024, a business feasibility study is a systematic analysis process carried out to evaluate the potential success of a business idea or project before allocating full resources. This process includes an assessment of various aspects such as market, technical, financial, management, as well as social and environmental impacts, with the aim of minimizing risks and ensuring that the proposed business can provide economic and non-economic benefits. 5 aspects as follows:

1. Technical Aspects

Simulation results using RETScreen software indicate that the use of corn cobs as an alternative fuel in a 6-ton capacity boiler yields reasonable technical performance, with an average seasonal efficiency of 75%, approaching the performance of palm kernel shells and candlenuts. The calorific value of corn cobs (approximately 15 MJ/kg) is lower than that of palm kernel shells (16 MJ/kg). However, with proper processing and storage (moisture content <13%), the resulting energy output is still sufficient to support the steam pressure requirement for animal feed production of 1.4 kWh per metric ton.

2. Social and Environmental Aspects

In this social aspect, the utilization of unused and underutilized agricultural waste, through this research, can increase the added value of corn cobs. The use of corn cob biomass can reduce CO2 emissions and also help the government achieve its Net Zero target by 2050.

3. Financial Aspect

Although the initial investment costs are slightly higher due to technical adaptations to the feeding system and combustion chamber, this is offset by the lower price of corn cobs (Rp 700–1,000/kg) when sourced directly from farmers and delivered to companies, which deliver the raw material, corn, as the primary raw material in the animal feed production process, compared to palm kernel shells (Rp 1,400/kg).

4. Market Aspect

Demand for animal feed with a more competitive cost of goods sold (COGS) is very high. The use of cheaper alternative fuels such as corn cobs can lower energy costs. With energy efficiency strategies, companies can offer lower feed prices or maintain higher profit margins. This provides greater competitiveness in the national feed market while expanding distribution segments.

5. Management Aspect

The management aspect of using corn cobs as a boiler fuel substitute focuses on strategic decision-making, including operational planning, raw material procurement, and energy efficiency evaluation. Management plays a role in ensuring a stable and affordable supply of corn cobs, while also monitoring system performance through software-based monitoring such as RETScreen. Management's success in managing this transition will directly impact production cost efficiency, product competitiveness, and the company's long-term sustainability.

The results of the business feasibility study obtained through economic analysis provide a quantitative overview of the potential financial benefits of corn cob substitution. To

complement this analysis and ensure that decisions are not solely based on financial aspects, this study continued with a SWOT analysis to identify internal and external factors that could impact the implementation of fuel substitution operationally and strategically. A SWOT analysis is a strategic planning tool used to identify internal strengths and weaknesses, as well as external opportunities and threats that influence organizational decision-making. Through this analysis, companies can understand their strategic position and prepare mitigation measures against potential risks that could impact business performance and sustainability (Zainuri & Setiadi, 2023).

1. Strength

Corncoobs are relatively abundant as an agricultural waste and a primary raw material for animal feed, offering potential for sustainable use. Furthermore, the cost of corncoobs tends to be lower than that of primary biomass, allowing for lower energy costs and Cost of Goods Sold (COGS). Their use as a substitute fuel also doesn't require significant modifications to existing boiler systems, allowing for implementation without complex technical changes.

2. Weakness

Despite its potential as a substitute fuel, corncoobs have a lower calorific value than palm kernel shells and candlenut shells, so their dominant use can reduce boiler efficiency. Furthermore, the quality of corncoobs is significantly influenced by moisture content and post-harvest handling, potentially impacting combustion stability. This study also has limitations because it did not include direct operational trials, so the analysis focused on a simulation-based economic feasibility study.

3. Opportunities

Utilizing corncoobs as a substitute fuel opens up opportunities for implementing green manufacturing principles by optimizing underutilized agricultural waste. Furthermore, the results of the RETScreen simulation-based economic feasibility analysis indicate potential energy cost savings, providing added financial value. The flexibility of fuel procurement through a blending system (biomass co-firing) also allows companies to adjust fuel composition according to supply availability and operational needs.

4. Threats

Threats to corncob substitution primarily relate to supply uncertainty, influenced by seasonal factors and fluctuations in alternative biomass prices in the market. Furthermore, there is a risk of reduced system efficiency if the proportion of corncob substitution is not optimally controlled, given the differences in combustion characteristics compared to primary biomass. Therefore, managing fuel composition and adapting procurement strategies are crucial in mitigating these potential risks.

To ensure the validity of the results of this study, data triangulation was used, namely a validity test between data obtained by the researcher, the results of data analysis by the researcher, interviews with the head of the HSE division, and the head of the Control Room. Triangulation in this study was carried out through four approaches: source triangulation, method triangulation, and theory triangulation. According to Husnullail et al. (2024), triangulation is a method of examining data by using other sources or information as a comparison to verify existing data. This data triangulation has four indicators used to test its validity, the data consisting of the following:

1. Source triangulation, a form of triangulation used to verify data by comparing information from various informants. This process involves checking data obtained from various sources, both from informants and supporting documents. In this study, source triangulation was conducted through direct observation to obtain relevant company documents and support the analysis, as well as the addition of literature from previous studies to increase the robustness of the data needed to analyze the economic feasibility of corncoobs as a boiler fuel substitute.

2. Method triangulation was conducted by combining a quantitative approach through software simulation (RETScreen). The use of RETScreen software enabled in-depth analysis of the technical, financial, and environmental parameters of fuel substitution scenarios.
3. Theoretical triangulation was applied by linking research findings to relevant theories in operational management, energy efficiency, and renewable energy utilization. For example, the theory of production efficiency according to Christopher J. O'Donnell (2018) and sustainable management, according to Kampan Mukherjee's ebook *Sustainable Operation Management 2024*, posits that green manufacturing is a production process that minimizes environmental impact, conserves energy and natural resources, and ensures employee safety and comfort at work. This is concluded by examining the economic feasibility of renewable energy innovations and environmentally friendly packaging.
4. Triangulation between researchers was used to enrich the data in this study by involving relevant parties in the information gathering process. This study used interviews to validate data collected directly, boiler technical adjustments, and literature. This was done by involving the Head of HSE and the Head of the Boiler Control Room to verify the consistency between company documents and direct observation results.

The validity test of data triangulation conducted through a comparison of simulation results, literature studies, and in-depth interviews with technical operators and production managers showed consistency between real conditions and simulation results, thus increasing the credibility of the research results. The validity of the method in this study was strengthened by the official recognition of the use of RETScreen Expert by the Ministry of Energy and Mineral Resources (KESDM) through PPSDM KEBTKE, in collaboration with the OJK Institute and OECD CEFIM. The Ministry of ESDM held RETScreen Expert Certification Training at the Santika Hotel in Bogor, which was attended by employees of the Ministry of ESDM, OJK, and OECD.

According to Christopher J. O'Donnell's book *Productivity and Efficiency Analysis* (2018), economic and operational analysis is used to assess the extent to which an entity—whether an individual, a company, or an industry—is able to convert inputs into outputs. O'Donnell explains that production efficiency is divided into two main categories: technical efficiency and cost efficiency. Technical efficiency assesses a production unit's ability to maximize output from a given set of inputs or minimize the inputs used to produce a given output. Meanwhile, cost efficiency measures the extent to which a production unit can select the most economical combination of inputs to produce the desired output. Cost efficiency is achieved when a production unit is not only technically efficient but also able to reduce total costs based on prevailing input prices. As a practical step, companies are advised to conduct phased trials with scenarios that balance costs and costs. Regular, data-based monitoring is necessary to assess the actual impact on production efficiency and costs. Managing fuel substitution also requires good coordination between production, logistics, and energy management departments to achieve optimal results. According to research by Faris and Handayani (2022), measuring production efficiency plays a strategic role in increasing a company's competitiveness. By optimizing input usage without compromising output quality or quantity, companies can reduce operational costs, increase profit margins, and strengthen their competitive position in the market. Energy efficiency is seen as a long-term strategy for reducing emissions, as the more optimal a system is in converting energy into output, the lower the fuel requirement and the lower the emissions (Ramadhan et al., 2024). According to research by Barokah and Takarini (2025), the use of software technology that integrates company needs, raw material availability, and optimal composition ratios for boilers can improve operational efficiency. This technology allows for more measurable variable management, minimizing the potential for human error, while saving time typically required for manual record-keeping. Furthermore, to reduce carbon emissions around the company, consideration can be given to the use of green open spaces and planting plants that absorb carbon emissions around the factory (Ramadhan and Purnomo, 2025).

CONCLUSION

The results of the RETScreen simulation-based economic feasibility analysis indicate that partial substitution of boiler fuel with corn cobs at PT XYZ Tbk. has the potential to reduce energy costs and increase the cost efficiency of animal feed production. Implementation is considered technically and financially feasible if implemented through a mixed scheme (co-firing) with palm kernel shells and candlenut shells to maintain boiler efficiency. The use of corn cobs also supports the principles of green manufacturing through the optimization of agricultural waste. Therefore, the company is advised to conduct phased trials with controlled substitution proportions and establish sustainable supply partnerships. Further research can develop this study through direct operational testing and a Life Cycle Assessment (LCA) approach for a more comprehensive environmental impact evaluation..

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