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Evaluating Profitability of Red Mud Based Geopolymer Brick by Using The Cost Benefit Analysis Framework

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Abstract: Red mud is a byproduct of Bayer process in alumina refinery which become a major problem in the industry. The waste causes alumina refinery to spend significant amount of capital and operational expenditure to handle and was historically have caused environmental damage to its surrounding environment. To fill the research gap, this work is design to define the cost and benefit of producing geopolymer brick based of red mud by using the Cost Benefit Analysis framework. The cost is determined by the capital and operational expenditure of constructing a geopolymer brick factory and benefit was determine by the amount of cashflow the factory would generate. The work is done in PT CBJ, a new alumina refinery based at Mempawah, West Kalimantan, Indonesia which in the future will produces approximately 30 million tons of red mud. The research showed the proposed project will potentially generating a positive present value cashflow worth $126,159,703.58 from processing an annual 1.5 million ton of red mud and $901,318.85 from 6,892 ton of red mud annual processing. However, the BCR only shows 1.02 and 1.03 ratio from both scenarios. Additionally, the sensitivity analysis shows some variables are way too sensitive after price changes which conclude the project is risky to execute.

Keyword: Alumina Refinery, Red Mud, Geopolymer Brick, Cost-benefit analysis, Net Present Value, Sensitivity Analysis.

INTRODUCTION

Aluminum have become one of the most important metals in humans' modern society. Its utilization varies from transportation, construction or even food packaging. The reason of its varying usability comes from their unique physical and chemical properties. Aluminum is light weight, corrosion resistance, good ductility and on top of that, it is recyclable (Raabe et al, 2022). Aluminum can also be part of a based alloys with other metals to enhance the properties. Thus, it also been used in electronics, building materials and aerospace (Duan, 2024). With the wide range of usability, no wonder that the produced aluminum in history reaching nearly 1 billion tons and still circulating in our world (Reck and Graedel, 2012).

Aluminum just like other metals needs a manufacturing process to begin with. At its natural form, aluminum can be found in a bauxite ore. The bauxite ore itself contains not just aluminum, but also other impurities such as silica, iron oxide and magnesium. Bauxite can be differentiated into three types, gibbsite (Al (OH)3), boehmite (γ-AlO (OH)) and diaspore (α-AlO(OH)) (Abyzov, 2019). But before a bauxite ore could be processed into aluminum, there are a refinery process that should be conducted to gain the pure alumina powder which is the main material in producing aluminum. This refinery process is called the Bayer Process, a process involving a complicated physical and chemical process.

Bayer Process is the most commonly used methods to produces alumina (Liu et al, 2007) and it is responsible for 90% of the produced alumina worldwide (Wang et al, 2018). It is a process that was invented by an Austrian Chemist in the 1887, Carl Josef Bayer (Ghou et al, 2022).

However, while the Bayer Process is producing the valuable alumina powder which the firm and country wanted, the process also producing a byproducts/waste that form on the refinery process. When alumina is dissolved/digested from the bauxite, the residual materials from the bauxite will also be separated and discharged. This material contains iron oxide, silica, calcium carbonate, titanium dioxide, sodium aluminum silicate and calcium silicate (Den Hond et al, 2017). The appearances are white, brown or red depending on the iron oxide content (Li et al, 2020). The residual material is called the red mud.

Red mud is a liability both in operation and financial aspect in alumina refinery since it needed extra operational expenditure to maintain. Approximately, every 1 ton of alumina produces, there are 1.5 million ton of red mud discharge from the refinery process which accounts more than half of the bauxite content. Normally, after the red mud discharged, the waste will be transported and placed at a designated area called a landfill. Storing red mud in an open space requires a lot of space and resources (Wang and Liu, 2021). Furthermore, red mud is classified as a toxic waste that potentially causing environmental problems. In a scenario that all of the potential problems occurred, an alumina refinery could potentially face an additional loss which affecting their cashflow.

To deal with this problem, countries that have more experienced in the alumina industry such as China and India have conducted many research to reduces the amount of this particular waste stacked in a landfill by process the waste even further to become a product. Reducing the amount of red mud and slag volume means reduce in operational expenditure and additionally, reducing the environmental hazard probability and severity of the waste causes. Turning the alumina industry liability to an exciting new business opportunity. Recent studies of the red mud and slag confirmed that there are some ways to utilize both wastes, rather just being discarded without any utilization.

Studies shown that red mud is able to use in many sectors such as building materials, agriculture, environment and chemical industry (Liu et al, 2014. Khairul et al, 2019). Slag also could be used in construction building to become a concrete or fillers. One way to make red mud less hazardous is to extract the iron resources and rare earth metals which are also valuable (Wang and Liu, 2021). However, the technology to achieve this is still immature (Wang and Liu, 2021). Thus, one of the solutions that are mature to implement are applicating red mud in infrastructure/construction purposes. a broad study has confirmed that red mud is a viable application for unburned bricks, glass ceramics, cement, geopolymer materials and subgrade materials (Wang and Liu, 2021; Liu et al., 2017; Liu and Zhang 2011; Mukiza et al., 2019).

However, in utilizing both of this material to become a building material, a firm will have to spend significant capital to construct factory with its equipment in able to complete the proposed project. Moreover, to process a 1.5 million ton of red mud annually itself will cost a lot of operational expenditure in the process. Ultimately, it is a risky move for a company to spent a substantial amount of money to execute the project without a proper financial metric to benchmark the new business prospect profitability. In venturing a new business opportunity, the project should past a certain financial metric in able to deemed the project profitable. Thus, a firm must conduct a study to determine whether the benefit of utilizing both wastes are greater than the cost spent. This is called a Cost-Benefit Analysis.

Cost-Benefit Analysis is a method to determine whether the benefit of an action is superior or inferior to its cost (Hanley and Barbier, 2009). If the cost is greater than the benefit generated on a project, than the proposed project is not worthy to invest in the first place. However, if the benefit is greater than the cost, a firm can continue to proposed the project further and is worthy to invest. With 1.5-million-ton red mud and 16.200-ton slag annually, PT. CBJ have a lot of potential for utilizing their waste to become a usable product. Not only it potentially generates revenue for the company, but also reduces the environmental issue that cause by stacking this waste in a landfill. Ultimately, if the company succeeded to process their refinery process waste into a product. The project could be a blueprint for a better and more environmentally friendly refinery process in Indonesia and the world.

METHOD

Data Collection

The authors incorporating the Mix-Method data collection in this research to fill the data that is needed in the cost-benefit analysis calculation. Quantitative data is gathered to determine the society willingness to buy the red mud geopolymer brick and how the price sensitivity it has if the geopolymer brick is more expensive than the traditional fired brick or the more expensive material like Hebel. Qualitative data is collected in PT CBJ to determine the rate of red mud transportation and operating cost such as water and electricity to determine the cost of red mud geopolymer brick produces. The data mentioned belongs to the primary data, while the secondary data is taken from the existing literature to gather the cost for machinery used and operational expenditure to produce the cost structure in determining the initial investment.

Quantitative Method

As mentioned above, quantitative method is used to determine the society willingness to purchase the red mud geopolymer brick. While the brick is innovative to produce, we do not know for certain if the society is accepting a seem “dangerous” material to construct their house. A questionnaire is constructed with a close-ended question and Likert scale to get an in-depth view of how well they know the red mud material and the danger lies it have. Next, the question will be around the society purchase intention for the geopolymer brick. The advantage is stated, such as the superior compressive strength and its resistance towards acid attack compared to the traditional brick, then a question is asked to the subject if they are willing to buy the red mud brick with the advantages stated. Price sensitivity is also analyzed by these questions to see how far they willing to purchase if the brick is more expensive than a traditional brick. The question is not focusing for a market acceptance. Rather, the question is generating the selling price for the brick so the profit in cash inflow could be identified for the cost-benefit analysis.

Qualitative Method

In qualitative method, the question asked is in a form of open-ended question to obtain the opinions of expert regarding the red mud geopolymer brick. The priority in this interview is from Finances, Construction and Red Mud Tailing Department since these department are expert involve and expert in red mud. Finances are interviewed to gain the missing variables in operational expenditure such as electricity, water, logistics and other hidden cost to complete the cost structures. The benchmark value of financial metrics is obtained to determine the minimum value for the project needed to reach. Furthermore, additional question will be asked regarding the financial readiness of the company.

Red Mud Tailing Department is interviewed to gain more insights of the material from its potential usage and danger that could happen in PT CBJ. Because the employee in this department has a long experience in handling red mud waste, the previous work experience is asked to validate the potential danger that have been stated in the literature and the mitigation that will be done in PT CBJ if the environmental hazard is occurring. Finally, construction expert is interviewed to gain data and opinions on how should the red mud geopolymer brick produced. What advantages and value could the red mud geopolymer brick give in construction activity.

Research Design

The research begun with the problem identification of red mud and PT CBJ itself through the preliminary study of existing journals about red mud and information that collected in PT CBJ. Next step was to gathered the data by quantitative and qualitative methods. Quantitative method is design to determine the price which society willing to pay for the brick and qualitative methods are used to gathered operational cost of PT CBJ. After all the variables are gathered, cost benefit analysis was conducted. The first step is to define the net cash flow each year for 20 years. the net cash flow equation is;

Net Cash Flow = Cash Inflow - Cash Outflow

Cash Inflow = Revenue from brick sold

Cash Outflow = Capital Expenditure + Operational Expenditure / Operational Expenditure + Penalty Cost

Other than that, other variables which PT CBJ should pay such as taxes (for the factory to initial run) or subsidies (if any) should be calculated inside the initial cost. Cash Inflow is determined by the revenue made from how much brick that were sold the following equation are;

1st year Net Cash Flow = Initial Cost/Capital Expenditure + Operational Expenditure

Initial Cost /Capital Expenditure= Equipment Purchase Prices + Installation Cost + Other Upfront Cost

Operational Expenditure = Raw Material Cost + Electricity Cost + Labor Cost +Maintenances and Spart Parts Cost +Marketing and Sales Fees + Taxes

After the net cash flow for 20 years are calculated, all of the net flow was compiled. To determine the money value from its 20-year run, the NPV was calculated with a discount rate of 8.5% (hurdle rate provided by PT CBJ) to calculate the Net Benefit in the present time. The equation is;

$$NPV = \sum_{t=0}^{n} \frac{Ct}{(1+r)^t} - C0$$

Where:
Ct = Cash inflow at time t
t = Time period (years)
r = Discount rate (or required rate of return)
C0 = Initial investment (cash outflow at time 0)

In other word, if we can summarize the equation into one. The equation to quantified the net benefit from the whole project could be summarized as;

Net Benefit (CBA) = Present Value of Benefit (PVB) – Present value of Costs (PVC)

$$\text{Net Benefit (CBA)} = \left(\sum_{t=0}^{n} \frac{Bt}{(1+r)^t}\right) - \left(\sum_{t=0}^{n} \frac{Ct}{(1+r)^t}\right)$$

Where:
Bt = Benefits at time t
Ct = Costs at time t

r = Discount rate (time value of money)
t = Time period (years)

To determine whether the project is profitable or not, 2 indicators which are Benefit to Cost Ratio (BCR) and Internal Rate of Return (IRR) become a benchmark to evaluate the project viability. BCR is a financial metric that derived from comparing the expected benefits to the associated costs. If the value is bigger than 1, the project is profitable, if the value is 1, the benefits equal the cost that spent, but if the value is less than 1, the project cost is outweighing the benefit and hence it is financially not viable. The BCR formula are;

$$BCR = \frac{Total\ Benefit\ (Present\ Value\ Cash\ Inflow)}{Total\ Cost\ (Present\ Value\ Cash\ Outflow)}$$

The Internal Rate of Return (IRR) is the discount rate which the NPV of the cashflow equals to zero and used to evaluate the profitability. Normally, a company would set standard on the IRR percentage to reach. If the IRR is the same or bigger than the IRR set by the company policy, than the project is viable to go. However, if it's not able to reach the standard, the project is not viable to go. The formula for IRR is;

$$NPV = \sum_{t=0}^{n} \frac{Ct}{(1+IRR)^t} = 0$$

Where:
Ct = Cash flow at time t (inflows and outflows)
t = Time period (from 0 to n, where n is the number of periods)
IRR = Internal Rate of Return
n = The number of periods or years

Additionally, Profitability Index (PI) is used to compliment the other financial metric. While BCR is dividing Benefit with Cost, PI is dividing the present value of future cash flow with the initial investment (CAPEX and other upfront cost). The metric rules are very similar to BCR with the benchmark score is more, same or less than 1. The formula is;

$$Profitability\ Index = \frac{Present\ Value\ of\ Benefit}{Initial\ Cost}$$

Payback Period (PP) is used to determine the breakeven point, which means in how much time does the firm could regain their initial cost from the incoming future cash flow. The formula of Payback Period is;

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Cashflow}$$

Sensitivity Analysis was done to test the integrity of the project by changing the variables that effected the financial metrics that used. The variables are changed in various degree until the financial metrics resulting equal or below the benchmark score needed. The variables then were classified as two types depending of its sensitivity. Sensitive variables are classified as variables which resulting in equal or negative financial metrics from its benchmark score after 100% increase and flexible variables which can withstand more than 100% increase.

The sensitive variables then are tested further by another sensitivity analysis which consist two or more sensitive variables, this is called the multiple variable sensitivity analysis. Two or more sensitive variables are simultaneously changed in order to create various scenarios that could happen. In this analysis, the previous financial metrics (NPV, BCR, IRR, PP and PI) are also tested. Since the initial cost/CAPEX are also a major part of the cost structure regardless of the sensitivity, the variables were also tested in the analysis along with other various sensitive variables. The worst and best scenarios are examined in all of the random scenario that set.

The research method contains the type of research, sample and population or research subjects, time and place of research, instruments, procedures, and research techniques, as well as other matters relating to the method of research. This section can be divided into several sub-chapters, but no numbering is necessary.

RESULTS AND DISCUSSION

Analysis

1. SWOT Analysis

Table 1. Swot Analysis of PT CBJ

Internal	**Strength** • Strategic partnership which links the supply chain of bauxite ore of PT A to PT IAA Aluminum Smelter. • Listed as one of the strategic national projects in Indonesia. • Construct with a more modern technology and equipment in alumina refinery. • Equipped with more automation technology, making it less labor to operate. • Guarantee buyer from PT IAA and MI Trading	**Weaknesses** • Single-line operation • Less production capacity than competitor • Inferior build quality compared to a European Refineries • Does not have an independent port for logistic operation • A relatively far tailing disposal facility which increasing the operational cost
External	**Opportunities** • Approximately 1,6 billion ton of bauxite resources in Indonesia to process. • Government support as the Indonesian Government favors the downstream processing and value addition • A relatively new business in Indonesia with less competitor. • High alumina price and market demand.	**Threats** • Some refineries are currently on project which adding to the competition in Indonesia • Red mud disposal that potentially effecting the environment • New in the operation • Changing regulation of down streaming bauxite to add value

2. PESTLE Analysis

a. Political

The Indonesian government's support for the processing of local minerals, such as bauxite, is an advantage for PT CBJ. This policy, coupled with trade partnerships with large markets such as China, supports demand for alumina exports. In addition, incentives such as tax deductions and subsidies provide opportunities to improve the sustainability of operations.

b. Economic

Global demand for aluminum, which is used in the construction and automotive industries, has a positive impact on alumina demand. However, exchange rate fluctuations can affect export revenues and equipment import costs. PT CBJ's operations also boost local economic growth by creating jobs and triggering demand for related services.

c. Social

PT CBJ's operations provide social benefits through job creation and local skills development. However, there are challenges related to community relations, such as impacts on the environment and water supply. Commitment to the safety and health of employees and surrounding communities is an important priority.

d. Technological

Innovations in alumina processing methods can improve efficiency and reduce costs. Investments in digitization and automation also have the potential to improve safety and smooth operations. Waste management technology, such as red mud, is an important area to support environmental sustainability.

e. Legal

Compliance with environmental regulations and Indonesian labor laws is imperative for PT CBJ to avoid legal sanctions and maintain good labor relations. Dynamic tax and mineral export policies also affect profit margins, so adaptive strategies are required.

f. Environmental
   Energy-intensive alumina processing affects the environment, making the adoption of environmentally friendly practices a necessity. Responsible waste management and attention to impacts on local ecosystems, including flora, fauna and water sources, are important to maintain community trust and meet regulations.

Interview

1. Financial Departement

   From the perspective of Finance Department, the utilization of red mud is a good opportunity for the company. They are assured if the red mud could be utilized, it will give an additional revenue to the company and lowering the company's cost in handling the waste. The financial readiness of the company to prepare the funding for this project are depended on the CBA that done. Although PT CBJ will operate in 2025 and the cash is not available for the project, the finances team assure that there are many ways to fund the project such as bank loan or the shareholder loan. The utilization of waste is surely attracting another stakeholder to invest in the project.

   From the interview, variables that is advised and identified by AL are capital expenditure to create the factory, cost of goods sold such as raw materials, labor, transportation, overhead and maintenances. Other such as permits and environmental cost could also be listed in the cost. The hauling cost of red mud to Toho is stated $10 per ton, the cost of tailing landfill itself for 1 year capacity is $10 million and the assumption of lost if the plant is not operatable because of the failure by the tailing facilities are $1.1 million per day. The penalty cost by environmental hazard is not identified in the interview since the finance department did not know the number. However, according to The Environmental Protection, particularly Law No. 32 of 2009 on Environmental Protection and Management, the cost/fine is up to $650 thousand and if the damage is permanent, the fine is up to $975 thousand. The collected data from the finances team can be summarize;
2. Red Mud Trailing Departement

   SP, who has been handling red mud waste since 2014 at PT H Alumina Refinery, mentioned that red mud can be used to make bricks, as he witnessed in China. There, bricks are made with traditional methods using high temperatures, although geopolymer methods have not yet been applied. At PT H, red mud is used as a planting medium for chili peppers through a CSR program. If PT CBJ succeeds in producing bricks from red mud, this will be the first innovation in Indonesia, opening up new income opportunities.

   SP noted that the short-term impact of red mud on the environment is minimal, although there was an incident during the rainy season that led to contamination of the drainage system by caustic soda, killing cultured fish. Long-term impacts have not been identified as operations have only been running for 10 years. PT CBJ has taken mitigation measures, such as the installation of water pH monitoring wells and research cooperation with Tanjungpura University. SP is confident that red mud-based bricks will be safe to use in solid form, with no risk of toxicity due to the absence of leaching.
3. Construction Departement

   Factor Currently, there are two types of brick that are available in the market. These are the traditional fired brick and Autoclaved Aerated Concrete (AAC) Block. AAC Block are also known as light brick or hebel in Indonesia. Primarily, it is consisting of cement, lime, sand and water. The advantages of AAC Block are they are lightweight and have a bigger volume. Which means, in the construction phase, the application of AAC Block are faster since they occupying much more space per brick putted and is light, making the applicator giving less effort and time. It is fire proof for up to 30 minutes before fire could burned it out. Lastly, it offers a greatest compressive strength at up to 5 MPa. However, the disadvantages of this material are it is more expensive than the traditional fired brick, it also does not sustain dynabolt or nails pretty well like fired brick because of the brittleness. This material are also the chosen brick to build some facilities/buildings in PT CBJ according to KW.

Fired brick wAAhile has some disadvantages like a smaller compressive strength at 2.5 MPa and is smaller in size which make it more time consuming to applied, it also has some advantages which the AAC Block does not have. It sustains well for application of dynabolt or nails, have a good ductility (less brittle) and is cheaper in price. Which make it still a choice for some people even KW. He although are a construction specialist, chosen fired brick rather than AAC Block since it can withstand dynabolt or nails better.

Surveys

The survey involving 206 respondents aimed to gauge customer interest in geopolymer bricks and price sensitivity. Results:

1. Respondent Demographics: The majority of respondents were aged 26-35 years old (47.6%) and mostly from Jabodetabek (41%). Male respondents dominated with 55.1%, and most were in engineering and law (18.4% each).
2. Home Ownership: Most respondents (77.9%) own a house, with the main building material being traditional firebricks (49.4%) or hebel/AAC block (43.3%).
3. Acceptance of Geopolymer Bricks: After being informed about the process and advantages of geopolymer bricks, majority of the respondents agreed (57.3%) or strongly agreed (40.3%) to use them. The average score of 4.37 indicates high acceptance of this product.
4. Acceptance of Geopolymer Bricks to Reduce Environmental Impact: The majority of respondents strongly agreed (49%) and agreed (41.7%) to use tailings-based geopolymer bricks due to their benefits in reducing environmental hazards (mean: 4.35).
5. Use of Red Mud and Fly Ash Based Brick: After knowing the toxic content of red mud, majority of the respondents still strongly agreed (42.4%) and agreed (46.8%) to use geopolymer bricks (mean: 4.29).
6. Use if proven safe: Most respondents agreed (47.3%) and strongly agreed (40.5%) if these bricks are proven safe (mean: 4.25).
7. Attraction Due to Higher Compressive Strength: Majority agreed (42.2%) and strongly agreed (41.3%) to use these bricks because of their higher strength compared to traditional bricks and hebel (mean: 3.97).
8. Interests Despite Being More Expensive: Respondents are willing to use these bricks even though they are more expensive than traditional bricks, with 40.8% strongly agreeing and 35% agreeing (mean: 3.97).
9. Maximum Acceptable Price Increase: The majority of respondents accepted a maximum price increase of up to 10% (28.6%) and 15% (24.3%) over regular bricks.
10. Price Considered Reasonable: Most respondents (44.7%) chose Rp.7,000 as a fair price for RM-FA geopolymer bricks, compared to firebricks (Rp.600-Rp.3,000) and hebel (Rp.6,800-Rp.10,000).

Expenditure

1. Maximum Production Capacity Expenditure

The total cost of constructing and preparing for the first year of production is $ 493,777,565.88. Since PT CBJ did not have the available cash for the project. The firm have an option to loan the money from bank. The loan is set with an assumption of 7% interest per year and a loan term for 10 years. the total of principal and interest payment are $ 689,814,482.00 using the Equated Monthly Installment (EMI) method. Besides from the principal and interest, PT CBJ is mandatory for paying tax to the government. The tax is 22% from the gross profit. However, due to the Indonesian Government regulation that allowing new business to free themselves from tax, the CBA will implement a 10 years Tax Holiday to help the new business ease the company expenditure, especially since for the first 10 years the company needs to paid all of the debt. After the 10-year loan term ended, the company will need to pay the 22% tax to the government.

r = 7%/12 = 0.07/12 = 0.00583 (monthly interest rate)

n = 10 x 12 = 120 months

$$EMI = \$492{,}478{,}864.58 \times \frac{0.005833 \times (1+0.005833)^{120}}{(1+0.005833)^{120}-1}$$

$$EMI = \$492{,}478{,}864.58 \times \frac{0.011692}{1.015557}$$

EMI = $5,748,454.10

Total Amount Paid = 5,718,097.20 x 120 = $686,171,664.16

Table 2. The annual principal and interest payment to the bank scheme

Year	Principal Payment	Interest Payment
1	$ 35,260,670.32	$ 33,356,496.09
2	$ 37,809,667.03	$ 30,807,499.39
3	$ 40,542,930.92	$ 28,074,235.50
4	$ 43,473,782.67	$ 25,143,383.74
5	$ 46,616,505.94	$ 22,000,660.48
6	$ 49,986,416.92	$ 18,630,749.50
7	$ 53,599,939.04	$ 15,017,227.38
8	$ 57,474,682.97	$ 11,142,483.45
9	$ 61,629,532.45	$ 6,987,633.97
10	$ 66,084,736.33	$ 2,532,430.09

2. Minimum Production Capacity Expenditure

Table 3. Overall cost structure for minimum capacity production

Item	Cost
Initial Cost/CAPEX	$156,433.71
Contingency Fund (30%)	$46,930.11
Raw Materials	$1,630,923.93
Labor	$33,600.96
Electricity	$20,723.18
Maintenances and Spare Parts	$2,148.00
Logistics	$242,323.52
Marketing and Sales Fee (1%)	$221,536.54
Total Cost	**$2,354,619.96**

The total amount of the first-year capital and OPEX is $2,354,619.96. Because the amount is relatively small, the funding is set without loan from bank. Rather, using PT CBJ available cash. In this way, there are no bank principal and interest that will burden the company cashflow. Tax is also set 22% from the revenue that paid in each year to the government. If however, the cashflow are negative, PT CBJ did not need to pay the 22% tax to the Indonesia Government.

Cost Benefit Analysis and Scenario Analysis

1. Scenario A

The situation A where PT CBJ have to pay for the $10 dollar fee to PT S for the hauling and handling of the annual 1.5 million ton of red mud in Toho will generate cash outflow of $15 million dollar at the first year. However, if the rate is increasing 3% per year due to inflation, the cost of hauling and maintenances in the second year is increasing at $15,450,000 and at the year 20, the hauling and maintenances cost is at $26,302,590.80. the cumulative cashflow before discount rate for the 20 year of the operation is at $403,055,617.33. if the cashflow is discounted with a rate of 8.5% the Net Present Value

(NPV) of the total cost PT CBJ needed to pay by the money value of our time is $176,371,375.45.

2. Scenario B

PT CBJ plans to fully utilize red mud for geopolymer brick production by starting the construction phase in Year 0, which includes engineering, procurement, construction and commissioning of the plant. During this phase, the company receives no cash inflows and records expenses of -$33,515,841.71. In Years 1 to 10, brick production commenced with annual gross profit exceeding $60 million, rising from $61.1 million in year 1 to $77.4 million in year 10. However, net cash flow remained negative until year 5 due to bank principal and interest payments, before gradually turning positive from $190,000 in year 6 to $8.8 million in year 10. Nonetheless, the accumulated cash flow was still negative at -$72.6 million at the end of year 10.

After the principal and bank interest are paid off, the biggest expense is reduced, but PT CBJ has to pay 22% tax starting from year 11 after the tax holiday period ends. In years 11 to 20, net cash flow jumped from $8.8 million to $64 million in year 11 and continued to increase to $81.1 million in year 20. The accumulated cash flow became positive at $53.6 million in year 11, signaling the turning point of the project, with the payback period of the investment achieved in 11 years and 8 months. Total cash inflows over 20 years amount to $13.63 billion before discounting, with outflows of $12.99 billion, resulting in a net cash flow of $640.63 million. With a discount rate of 8.5%, the project recorded an NPV of $126.16 million, an IRR of 15.89% (exceeding the 8.5% benchmark), a PI of 3.76, and a BCR of 1.02, indicating the project is profitable despite its operating costs being much higher than the initial costs.

3. Scenario C

In Situation C, PT CBJ did not utilize red mud for geopolymer brick production, resulting in the leaching of toxic materials from the landfill, causing serious environmental impacts. Over 20 years, the total loss incurred amounted to $1.106 billion, with details: $350.7 million for reconstruction of the landfill with a capacity of 30 million tons of red mud, $352 million due to lost opportunities during the 6-month production shutdown for reconstruction, $350.5 million for transportation and maintenance of red mud, and $975,000 in legal fines. The initial cost of landfill reconstruction in Year 0 is $10 million for a capacity of 1.5 million tons, which increases to $17.5 million in Year 20 following 3% annual inflation. In addition, the daily opportunity cost also increases from $1.1 million to $1.93 million in Year 20. With a discount rate of 8.5%, the NPV of loss is calculated at $314 million, illustrating the significant financial risk of not optimally utilizing red mud.

4. Scenario D

In Situation D, PT CBJ produces geopolymer bricks from red mud based on the amount of slag available without involving bank loans, but still pays tax at 22% from the start of operations if the pre-tax cash flow is positive. In the first year, PT CBJ recorded a gross loss of $28,215.10 and paid no tax. From year two to year 20, gross profit increased from $132,065.84 to $224,843.12. Cumulative cash flow is negative until year 2, but turns positive by $24,463.18 in year 3, with start-up costs returning in year 4. By year 20, cumulative cash flow before discounting reached $2.4 million, with an NPV of $901,318.85 (8.5% discounting). The Profitability Index (PI) was 5.76, the Benefit-Cost Ratio (BCR) was 1.03, and the IRR was 43.65%, well above the benchmark of 8.5%. The project shows a payback period of 3 years assuming all bricks are sold, indicating high profitability and low investment risk.

5. Scenario E

In Situation E, PT CBJ utilized red mud for geopolymer brick production, but the residual red mud in Toho continued to cause environmental problems in year 20. The total loss due to environmental impact is $1.1 billion before discounting. Due to the smaller amount of red mud, transportation, maintenance, and reconstruction costs were reduced, so the net outflow decreased by 0.61% compared to Situation C, with the total net loss after inflows from brick sales profits being $1.099 billion. After discounting 8.5%, the net loss is calculated at $312.28 million, only a 0.56% decrease from the loss in Situation C. The change in NPV is not significant as the profits and volume of brick sales are not enough to offset the penalties and losses incurred by PT CBJ.

Sensitivity Analysis

Table 4. Variables and the tolerance types in the cost structure

Flexible Variables (> +/-100% changes)	Sensitive Variables (< +/-100% changes)
• Initial cost	• Operational Expenditure
• Labor cost	• Raw material cost
• Electricity cost	• Logistic cost
• Marketing and Sales Fee	• Pricing
• Maintenances and Spare parts	• Inventory Sold

Sensitivity analysis shows that some variables have high flexibility, while others are highly sensitive to changes in value. Start-up costs are flexible; at maximum capacity, a 100% increase in start-up costs still results in a positive NPV of $61,753,685.17, an IRR of 11%, and a BCR of 1.01, although the PI becomes negative. At minimum capacity, start-up costs can increase by 300% with the NPV remaining positive. In contrast, operating expenses are very sensitive; a 20% increase at maximum capacity leads to a negative NPV of -$39,336,432.96, while a 20% reduction increases the NPV to $291,655,840.11.

Logistics costs also affect the results significantly. At maximum capacity, a 20% increase leads to a negative NPV of -$73,734,625.72, while a 20% reduction increases the NPV to $326,054,032.88. Raw materials and prices are critical in the cost structure; a 2% increase in raw material prices or an inventory sale of only 97% causes the NPV to become negative. Sensitivity to NaOH price is also high, where a 10% increase reduces NPV to negative, but a 20% decrease increases NPV significantly.

The combined analysis shows that a 50% decrease in start-up costs can offset a 10% increase in operating expenses, resulting in financial metrics that remain positive. Price variations and sales levels greatly affect revenue. A 5% price decrease or sales 2% lower than target resulted in negative financial metrics. However, a 20% increase in price increased the flexibility of inventory sold to 85%, although at 80% price, all metrics remained negative. This shows that prices cannot be lowered further without risking losses.

Sensitivity analysis on the minimum capacity scenario shows a similar pattern of value flexibility as the maximum capacity, although slightly more flexible to changes in operating expenditure of up to +20%. A 50% decrease in initial cost with a 20% increase in operating expenditure still results in a positive NPV of $258,535.16, although the IRR and BCR decrease. However, if the operating expenditure increases by 20% and the initial cost increases by 500%, the NPV becomes negative, indicating the project is no longer viable. In contrast, a 50% decrease in initial cost and 80% decrease in operating expenditure almost doubles the NPV to $1,660,096.43, with the IRR jumping to 824%. This confirms that operating expenditure has a more significant impact on financial metrics than initial costs.

Sensitivity to inventory prices and sales also showed a large impact. A 20% price increase with 100% sales increases the NPV to 912% of its baseline value. However, at 80% inventory sold, the NPV becomes negative. A decrease in price or sales below 95% leads to negative financial metrics. Further testing showed that the price of $0.47 per brick was considered too low, as increasing the price by 20% could increase the NPV by 2337%.

Variable combination analysis showed that the use of NaOH, the most expensive raw material, greatly affected the financial results. Reducing the use of NaOH to 25% or 10% allows price flexibility and lower sales levels, still resulting in a positive NPV. In the minimum capacity scenario, a similar sensitivity pattern was found, where a reduction of NaOH to 10% with 70% of inventory sold still showed a positive NPV.

In the multiple scenario analysis, the three scenarios with the highest NPV were selected to evaluate PT CBJ's loss reduction due to the environmental impact of red mud. Although the sale of geopolymer bricks helped to reduce the loss by 1-6%, the result was still insufficient to cover the entire loss experienced by PT CBJ.

Implementation Plan

This subchapter outlines a comprehensive solution for PT CBJ to utilize red mud and slag waste in producing geopolymer bricks, structured using the 5W+1H framework. The solution involves converting environmental liabilities into valuable commercial products by leveraging geopolymer technology, which offers environmental and structural benefits. The project will be carried out over at least two years, starting with a feasibility study and market analysis in Phase 1 (Months 1-6), followed by the contractor tendering process in Phase 2 (Months 7-9). Phase 3 (Months 10-20) will focus on engineering, procurement, construction, and commissioning of the plant, and Phase 4 (Months 20-24) will involve performance testing to ensure the factory meets production capacity. The project will be implemented at PT CBJ's Mempawah facility in West Kalimantan, leveraging proximity to raw materials. Key stakeholders include the project management team, engineering, finance, marketing teams, and government bodies. The initiative aims to reduce environmental impact by processing waste materials, create economic opportunities by generating additional revenue, and improve operational efficiency by eliminating waste disposal costs. The implementation process includes feasibility studies, procurement, pilot testing, and scaling up production, with a focus on marketing the geopolymer bricks as a sustainable alternative in construction.

CONCLUSION

Red mud has been a liability to alumina refinery for a long time. Not only in terms of financial lost that a company needed to spent every year to maintain the waste, but also in terms the of environmental hazard that can be cause. Many attempts and research are done to reduce the loss from red mud waste by utilizing and recycling the waste and the most mature way from literature that existed are using red mud as a geopolymer brick material.

From the economic valuation using the Cost Benefit Analysis and other financial metrics. The geopolymer brick production in both capacity shows a relatively positive outcome. However, it is shown that the project is risky to execute in the base scenario. The NPV cost of red mud maintenances and transportation is $176,371,375.45, compared it with the cashflow generated from the maximum capacity is only $126,159,703.58 which generate less than the transportation and maintenances of red mud cost. Instead of risking $5,364,122,638.11 present value cost that only generate $0.02 cent of it, It is more attractive for PT CBJ to spend the $176,371,375.45 on red mud transportation and maintenances with no fuss to operate the geopolymer brick factory.

However, it is noted that the problem of low benefit that gain from the project is due to the brick pricing limitation of Rp.7000/$0.47 per brick and the NaOH uses. Sensitivity analysis shown that if the pricing could be increased 20%, the NPV is projected to $2,154,961,605.80 which give PT CBJ a profit of $0.36 from every dollar they invested. Another case also can be seen when the NaOH use dropped to 50% which resulting the NPV of $1,693,890,837.27. In order to do this, PT CBJ should strengthen their marketing campaign of geopolymer brick in able to increase their profit margin and do a research and development on how to decrease the NaOH usage or price in order to decrease the COGS for the brick.

At the minimum capacity, the NPV generated and other financial metrics followed the same pattern since the cost structure are similar. In case of environmental hazard is caused and maximum penalty to PT CBJ does occur, the cashflow generated from geopolymer brick factory is not sufficient to compensate all the lost PT CBJ could suffer. While the interview from the Tailing Department state that PT CBJ already take a preventive action for the red mud hazard, a more precise and consistent preventive action should be considered in order to reduce the possibility for the hazard to occur.

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