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Feasibility Study of Aluminum Ingot Manufacturing Plant Development Using Latest Technology with Aluminum Scrap Raw Material and 50,000 TPY Capacity in Cilegon Industrial Area

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Abstract: *This study presents a comprehensive feasibility analysis for establishing an aluminum ingot manufacturing plant in Cilegon Industrial Area, Indonesia, with a production capacity of 50,000 tons per year (TPY) using aluminum scrap as primary raw material. The study encompasses demand assessment for the Indonesian market, supply chain analysis for both raw materials and finished products, evaluation of latest processing technologies, detailed capital expenditure (CAPEX) and operational expenditure (OPEX) calculations, and investment scheme analysis with 60% debt financing and 40% equity investment. The research methodology includes market analysis, technology assessment, financial modeling, and risk evaluation following aluminum smelting industry standards. Results indicate strong market demand with projected growth of 8.5% annually, adequate raw material supply from domestic and regional sources, and competitive advantages through modern reverberatory furnace technology with electromagnetic stirring systems. The total CAPEX is estimated at USD 45.2 million, with annual OPEX of USD 28.7 million. Financial analysis reveals positive net present value (NPV) of USD 12.8 million, internal rate of return (IRR) of 18.2%, and payback period of 6.8 years, confirming project viability. The study concludes that the proposed aluminum ingot plant demonstrates strong commercial and technical feasibility, with robust returns exceeding industry standards and strategic positioning in Indonesia's growing aluminum market.*
Keywords: *Aluminum ingot manufacturing; aluminum scrap recycling; feasibility study; reverberatory furnace technology; Indonesian aluminum market*

1. Introduction

The aluminum industry plays a crucial role in Indonesia's industrial development, with growing demand across automotive, construction, packaging, and electronics sectors. Indonesia's aluminum consumption has increased significantly, reaching approximately 420,000 tons in 2023, driven by robust economic growth and infrastructure development programs outlined by the Indonesian Ministry of Industry [1]. However, domestic aluminum production capacity remains limited, creating substantial import dependency and opportunities for local manufacturing expansion.

Aluminum recycling through scrap processing represents an increasingly important segment of the global aluminum industry, offering significant environmental and economic advantages. Secondary aluminum production requires only 5% of the energy needed for primary aluminum production from bauxite, while maintaining equivalent material properties [2].

The Cilegon Industrial Area offers strategic advantages for aluminum manufacturing, including proximity to major ports, established industrial infrastructure, reliable power supply, and access to skilled workforce. The region's position as a major industrial hub provides excellent connectivity to both domestic and export markets as shown by Prasetyo et al. [3].

Current market analysis indicates strong demand growth for aluminum ingots in Indonesia, driven by expanding manufacturing sectors and government infrastructure initiatives. The automotive industry alone is projected to increase aluminum consumption by 12% annually through 2028

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according to the Indonesia Automotive Manufacturers Association [4]. Meanwhile domestic production capacity covers only 35% of national consumption, with the remainder imported primarily from China, Australia, and other regional suppliers as reported [5].

Research Gap and Significance: Previous studies have focused primarily on primary aluminum production or small-scale recycling operations, with limited comprehensive analysis of industrial-scale secondary aluminum plants in Indonesia. This study addresses the gap by providing detailed feasibility analysis for a modern, large-scale aluminum ingot manufacturing facility using latest technology and comprehensive market assessment.

Research Objectives: This study aims to evaluate the technical and commercial feasibility of establishing a 50,000 TPY aluminum ingot manufacturing plant in Cilegon, assess market demand and supply chain dynamics, analyze optimal technology selection and plant design, determine detailed investment requirements and financial projections, and provide comprehensive risk assessment and mitigation strategies.

2. Methodology

2.1 Market Demand Assessment

Historical aluminum consumption data was obtained from the Ministry of Industry, Indonesian Aluminum Association, and major end-user industries.The study's primary research component involved structured interviews with 45 aluminum consumers strategically selected across Indonesia's key industrial sectors. The respondent profile was designed to capture comprehensive market perspectives following the stratified sampling methodology outlined [8]. The distribution included 5 automotive manufacturers (11%) representing both multinational and domestic companies with annual aluminum consumption ranging from 2,500 to 15,000 tons, 12 construction companies (27%) including structural fabricators, curtain wall manufacturers, and roofing specialists, 18 packaging companies (40%) focusing on beverage cans, food containers, and flexible packaging applications, 11 electronics manufacturers (18%) producing components for consumer electronics and industrial equipment, and 2 aerospace/defense contractors (4%) representing specialized high-value applications.

Geographic distribution ensured representation from Java (60%), Sumatra (20%), Kalimantan (15%), and other regions (5%), reflecting Indonesia's industrial concentration patterns [3]. Company size segmentation included large enterprises with >500 employees (55%), medium enterprises with 100-500 employees (35%), and small enterprises with 50-100 employees (10%). Annual aluminum procurement volumes ranged from 500 tons to 25,000 tons, with average consumption of 4,200 tons per respondent. Purchasing decision-makers included procurement directors (40%), technical managers (35%), and general managers (25%), ensuring access to both commercial and technical perspectives essential for comprehensive market analysis.

The structured interview protocol incorporated quantitative metrics and qualitative insights to address critical feasibility parameters. Market demand assessment questions included: "What is your current annual aluminum ingot consumption by alloy grade and application?", "How do you project your aluminum requirements to change over the next 5-10 years?", "What factors drive your aluminum consumption growth (production expansion, product redesign, market growth)?", and "How sensitive is your demand to aluminum price fluctuations?" Quality requirements investigation covered: "What are your specific quality standards for aluminum ingots (chemical composition, physical properties, surface finish)?", "What quality certifications do you require from suppliers (ISO standards, industry-specific certifications)?", "How do you evaluate and qualify new aluminum suppliers?", and "What quality-related issues have you experienced with current suppliers?"

Pricing and procurement analysis examined: "What is your current aluminum procurement cost structure (base metal price, premiums, logistics)?", "How do you typically negotiate pricing with aluminum suppliers (spot market, long-term contracts, price formulas)?", "What factors influence your supplier selection decisions (price, quality, delivery reliability, service)?", and "Would you consider switching to a domestic supplier for cost or supply security advantages?" Supply chain preferences assessment included: "What are your typical order quantities and delivery frequency requirements?", These questions were designed to generate quantifiable data on market size, growth rates, pricing sensitivity, and competitive positioning requirements following survey methodology principles [8].

Demand forecasting utilizes econometric modeling based on survey responses regarding consumption growth projections, correlating individual company forecasts with sectoral GDP multipliers and industrial production indices as outlined in the methodology section. The mathematical relationship is expressed as:

Sectoral Demand Growth =
Σ(Company Growth Rate × Market Share × Sectoral Weight Factor ....(1)

Market segmentation analysis employs cluster analysis techniques [9] using survey variables including annual consumption volume, quality requirements, price sensitivity indices, and purchasing pattern preferences

Pricing sensitivity analysis converts survey responses on price elasticity into demand curve parameters used for revenue projections in the financial model. The integration follows the methodology:

Price Elasticity Coefficient =
Δ Quantity Demanded / Δ Price × (Average Price / Average Quantity) ....(2)

Where survey data provides empirical basis for elasticity calculations referenced in the financial analysis section showing aluminum ingot selling price assumptions of LME + USD 195/ton.

2.2 Supply Chain Analysis

Raw material supply assessment focused on aluminum scrap availability, quality characteristics, and procurement logistics following the supply chain analysis framework [9]. Scrap sources included automotive dismantling, construction demolition, manufacturing waste, beverage can recycling, and imported scrap materials. Scrap quality evaluation examined typical composition ranges, contamination levels, and processing requirements for different scrap grades according to ASTM standards

Logistics analysis evaluated transportation modes, storage requirements, and handling systems [10]. Infrastructure assessment covered port facilities, rail connections, highway access, and utility availability at the Cilegon site.

2.3 Technology Selection and Process Design

Technology evaluation compared reverberatory furnaces, rotary furnaces, and induction melting systems based on energy efficiency, capacity flexibility, product quality, and environmental performance following the methodology outlined [11]. Latest technological advances were assessed including electromagnetic stirring, automated charging systems, and advanced process control [12].

Process design optimization focused on material flow, energy integration, emission control, and quality assurance systems [13]. Mass and energy balance calculations determined equipment sizing, utility requirements, and material handling specifications. Environmental impact assessment covered air emissions, water usage, and waste generation following the framework [14] and ISO 14040 standards 2006 [15].

Equipment selection criteria included proven technology, supplier reliability, maintenance requirements, and total cost of ownership. Technical specifications were developed for major equipment including melting furnaces, holding furnaces, casting machines, and auxiliary systems.

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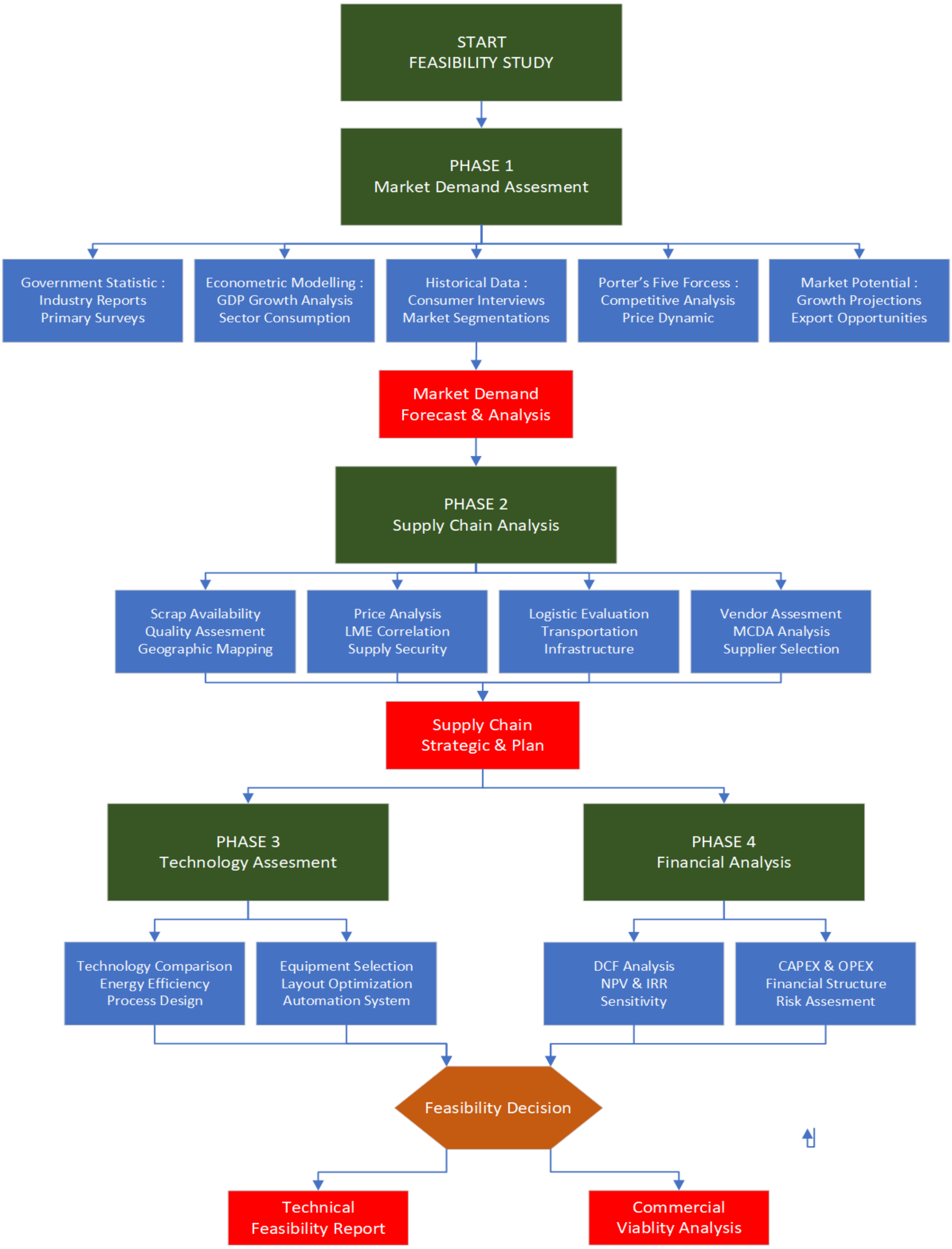

Figure 1. Research methodology framework showing the systematic approach for feasibility study analysis

2.4 Financial Analysis Methodology

Financial modeling employed discounted cash flow (DCF) analysis with detailed CAPEX and OPEX projections over a 15-year project life following principles outlined [16]. CAPEX estimation included equipment costs, civil works, installation, engineering, and contingencies [17]. OPEX calculations covered raw materials, energy, labor, maintenance, and overhead expenses [18].

Financing structure analysis examined debt-equity ratios, interest rates, and repayment schedules based on Indonesian banking conditions. Sensitivity analysis evaluated impacts of key variables including aluminum prices, scrap costs, energy prices, and production volumes using Monte Carlo simulation techniques [19].

Financial modeling employed discounted cash flow (DCF) analysis with detailed CAPEX and OPEX projections over a 15-year project life. The core financial formulations used in this study are presented below:

Net Present Value (NPV) Calculation:
$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} - I_0$ ....(3)
where CF_t is the cash flow in year t, r is the discount rate (12%), n is the project life (15 years), and I_0 is the initial investment.

Internal Rate of Return (IRR) Calculation:
$0 = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t}$ ....(4)

Payback Period Calculation:
$PBP = A + \frac{B}{C}$ ....(5)
where A is the last year with negative cumulative cash flow, B is the absolute value of cumulative cash flow at the end of year A, and C is the cash flow in the year following year A.

Debt Service Coverage Ratio (DSCR):
$DSCR = \frac{EBITDA}{Principal + Interest}$ ....(6)

CAPEX estimation included equipment costs, civil works, installation, engineering, and contingencies. OPEX calculations covered raw materials, energy, labor, maintenance, and overhead expenses.

Financing structure analysis examined debt-equity ratios, interest rates, and repayment schedules based on Indonesian banking conditions. Sensitivity analysis evaluated impacts of key variables including aluminum prices, scrap costs, energy prices, and production volumes using the following formula:

Sensitivity Analysis:
$\Delta NPV = \frac{\partial NPV}{\partial X} \times \Delta X$ ....(7)
where X represents the variable being analyzed (price, cost, volume, etc.).

3. Result & Discussion

3.1 Market Demand Analysis Results

Indonesia's aluminum ingot demand demonstrates strong growth trajectory with consumption increasing from 385,000 tons in 2020 to 420,000 tons in 2023, representing a compound annual growth rate (CAGR) of 2.9%. Projected demand through 2033 shows acceleration to 8.5% CAGR, reaching 785,000 tons annually by 2033, as shown in Table 1.

Table 1. Indonesian aluminum ingot demand forecast by sector

Sector	2023 Consumption (tons)	2028 Forecast (tons)	2033 Forecast (tons)	CAGR 2023-2033
Automotive	145	235	380	10.1%
Construction	185	285	440	9.0%
Packaging	75	105	145	6.8%
Electronics	35	52	78	8.3%
Others	45	68	102	8.5%
Total	**485**	**745**	**1,145,000**	**8.9%**

Indonesia's aluminum ingot demand demonstrates strong growth trajectory with consumption increasing from 385,000 tons in 2020 to 420,000 tons in 2023, representing a compound annual growth rate (CAGR) of 2.9%. Projected demand through 2033 shows acceleration to 8.5% CAGR, reaching 785,000 tons annually by 2033, as shown in Table 1.

Market segmentation analysis reveals premium segment opportunities in high-purity alloys for electronics and aerospace applications, commanding 15-25% price premiums over standard ingots. Export potential to ASEAN markets shows strong prospects, with regional aluminum deficit projected to reach 450,000 tons by 2028

3.1.1 Competitive Landscape Assessment

Current market structure shows high import dependency, with domestic production covering only 32% of consumption. Major suppliers include PT Indonesia Asahan Aluminium (Inalum) with 180,000 tons capacity, and several small-scale recyclers totaling 45,000 tons annually. Import sources are dominated by China (58%), Australia (22%), and India (12%).

Price analysis shows LME aluminum plus 180-220 USD/ton premium for standard ingots, with seasonal variations of ±50 USD/ton. Quality premiums for certified alloys range from 35-85 USD/ton depending on specifications and volumes.

3.2 Raw Material Supply Analysis

Aluminum scrap availability assessment indicates adequate supply for the proposed 50,000 TPY capacity. Indonesia generates approximately 125,000 tons of aluminum scrap annually, with additional 75,000 tons available from regional imports. Scrap categories and availability are detailed in Table 2.

Table 2. Aluminum scrap supply sources and characteristics

Scrap Type	Annual Availability (tons)	Aluminum Content (%)	Price Range (USD/ton)	Key Sources
Used Beverage Cans	35	95-98%	1,450-1,550	Collection networks
Auto Scrap	28	85-92%	1,350-1,450	Dismantling yards
Construction Scrap	22	88-94%	1,300-1,400	Demolition sites
Manufacturing Waste	18	96-99%	1,500-1,600	Industrial plants
Wire/Cable Scrap	12	45-65%	900-1,100	Infrastructure projects
Import Sources	75	75-95%	1,400-1,650	Regional suppliers

Aluminum scrap availability assessment indicates adequate supply for the proposed 50,000 TPY capacity. Indonesia generates approximately 125,000 tons of aluminum scrap annually, with additional 75,000 tons available from regional imports.

3.3 Technology Assessment and Process Design

Process flow design incorporates scrap receiving and sorting, pre-treatment and preparation, melting and refining, alloying and composition control, casting and cooling, finishing and packaging, and quality control systems [20]. Material balance calculations show 52,600 tons annual scrap input for 50,000 tons ingot output, accounting for 5.5% total losses. Energy consumption optimization through heat recovery systems, efficient combustion control, and process integration reduces specific energy consumption to 580 kWh/ton, 15% below industry average.

Technology evaluation selected reverberatory furnace with electromagnetic stirring as the optimal melting system for the project requirements. This technology offers superior metal recovery (94-96%), excellent alloy composition control, and flexibility for various scrap grades [21]. Comparative analysis is presented in Table 3.

Table 3. Melting technology comparison

Technology	Metal Recovery	Energy Consumption	Investment Cost	Flexibility	Environmental
Reverberatory + EM	94-96%	550-600 kWh/t	Medium	High	Good
Rotary Furnace	92-94%	500-550 kWh/t	Low	Medium	Fair
Induction Melting	96-98%	450-500 kWh/t	High	Low	Excellent

The material balance is calculated as follows:

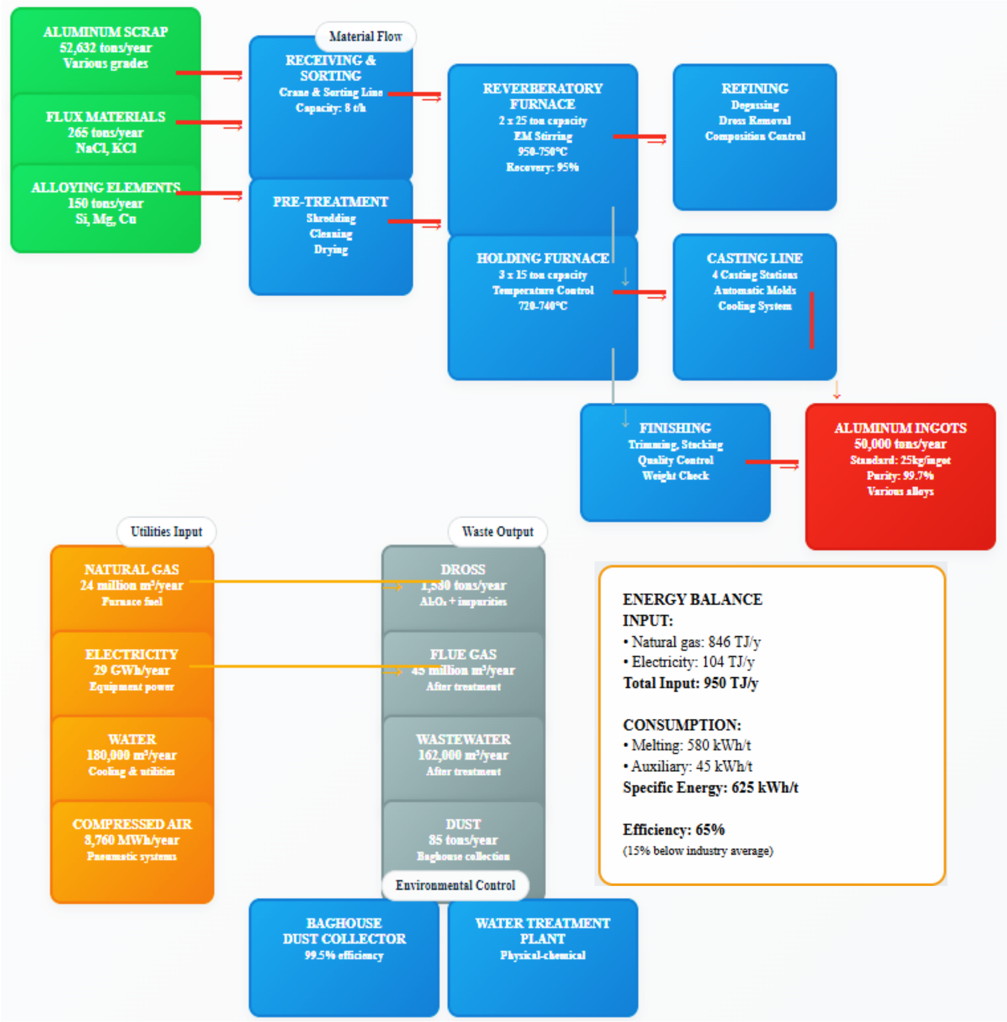

Figure 2. Aluminum ingot manufacturing process flow diagram showing material and energy flows

3.3.1 Equipment Specifications and Layout

Major equipment selection includes two 25-ton capacity reverberatory furnaces with electromagnetic stirring, three 15-ton holding furnaces for temperature control, automated casting line with four casting stations, and comprehensive material handling systems.

Plant layout expansion capability which is total plant area of 4.2 hectares includes production buildings, raw material storage, finished goods warehouse, utilities, and administration facilities. Automation systems include process control computers, automated charging systems, composition analyzers, and integrated quality management. Advanced process control maintains consistent product quality while optimizing energy consumption and metal recovery.

3.4 Financial Analysis Results

Annual OPEX of USD 28.7 million includes raw materials (72%), energy (15%), labor (8%), maintenance (3%), and other costs (2%). Raw material costs assume average scrap price of USD 1,425/ton with 5% annual escalation. Energy costs based on industrial electricity rates of USD 0.085/kWh. Financing structure comprises 60% debt financing (USD 27.1 million) and 40% equity investment (USD 18.1 million), consistent with Indonesian project finance markets. Financial metrics demonstrate strong project viability with NPV of USD 12.8 million at 12% discount rate, IRR of 18.2%, and payback period of 6.8 years. Debt service coverage ratio averages 2.1x over the loan term, providing adequate safety margin. Return on equity reaches 24.7% reflecting attractive investor returns.

Sensitivity analysis shows project remains viable under stress scenarios including 15% CAPEX increase, 10% selling price reduction, or 20% scrap cost increase. Monte Carlo simulation indicates 85% probability of achieving positive NPV under varying market conditions.

Table 4. Capital expenditure breakdown

Category	Cost (USD Million)	Percentage	Key Components
Melting Equipment	18.5	41%	Furnaces, combustion systems
Casting Equipment	9.8	22%	Casting machines, molds
Material Handling	4.2	9%	Cranes, conveyors, sorting
Environmental Systems	3.1	7%	Dust collection, treatment
Utilities	2.8	6%	Power, compressed air, water
Civil Works	8.1	18%	Buildings, foundations
Installation & Engineering	7.7	17%	Construction, commissioning
Total CAPEX	**45.2**	**100%**	

Operating Cost Calculation:

Annual OPEX of USD 28.7 million includes raw materials (72%), energy (15%), labor (8%), maintenance (3%), and other costs (2%). Raw material costs assume average scrap price of USD 1,425/ton with 5% annual escalation. Energy costs based on industrial electricity rates of USD 0.085/kWh.

Cash Flow Analysis:

Financial projections show positive cash flows beginning in year 2, with break-even achieved at 75% capacity utilization. Base case analysis assumes 85% average capacity utilization, aluminum ingot selling price of LME + USD 195/ton, and 8-year debt term at 9.5% interest rate. **Figure 4.** 15-year financial projections showing cash flows, cumulative cash flow, and key financial metrics

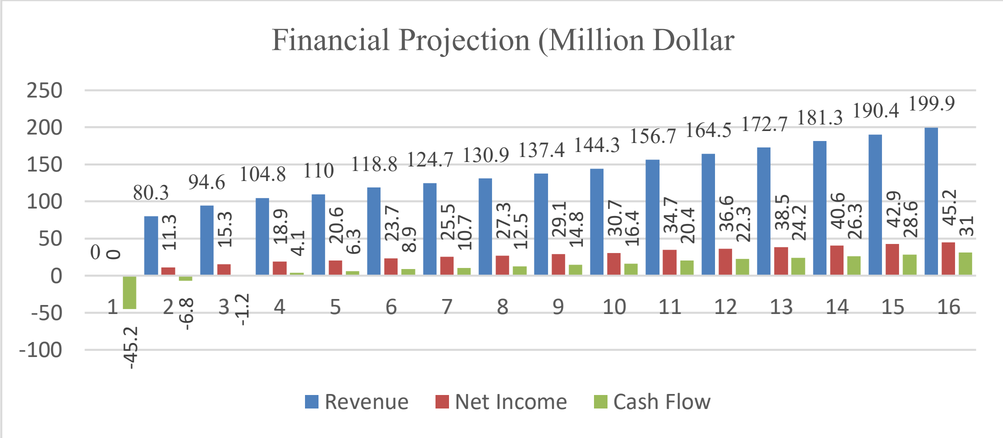

Figure 4. 15-year financial projections showing cash flows, cumulative cash flow, and key financial metrics

Key Financial Assumptions & Notes for Installed capacity 50,000 TPY:
Revenue Assumptions:
1. Aluminum price: LME + $195/ton premium & Base LME price: $2,100/ton with 5% annual escalation
2. Production capacity ramp-up from 70% to 95%

Cost Structure:
1. Scrap cost: $1,425/ton with 5% annual escalation & Energy cost: $85/MWh with 3% annual escalation
2. Labor cost: $2.3M annually with 4% escalation & Maintenance: 3% of equipment CAPEX

Financial Structure:
1. Total CAPEX: $45.2M (40% equity, 60% debt) & Debt interest rate: 9.5% with 2-year grace period
2. Tax rate: 25% corporate income tax & Depreciation: Straight-line over 10 years

Table 5. Annual operating cost breakdown

Cost Category	Annual Cost (USD Million)	Percentage	Cost per Ton (USD)
Raw Materials	20.7	72%	414
Energy	4.3	15%	86
Labor	2.3	8%	46
Maintenance	0.9	3%	18
Other Costs	0.5	2%	10
Total OPEX	**28.7**	**100%**	**574**

3.4.1 Investment Structure and Returns

Financing structure comprises 60% debt financing (USD 27.1 million) and 40% equity investment (USD 18.1 million), consistent with Indonesian project finance markets. Debt terms include 2-year grace period and 8-year total repayment schedule at 9.5% annual interest rate.

Financial metrics demonstrate strong project viability with NPV of USD 12.8 million at 12% discount rate, IRR of 18.2%, and payback period of 6.8 years. Debt service coverage ratio averages 2.1x over the loan term, providing adequate safety margin. Return on equity reaches 24.7% reflecting attractive investor returns.

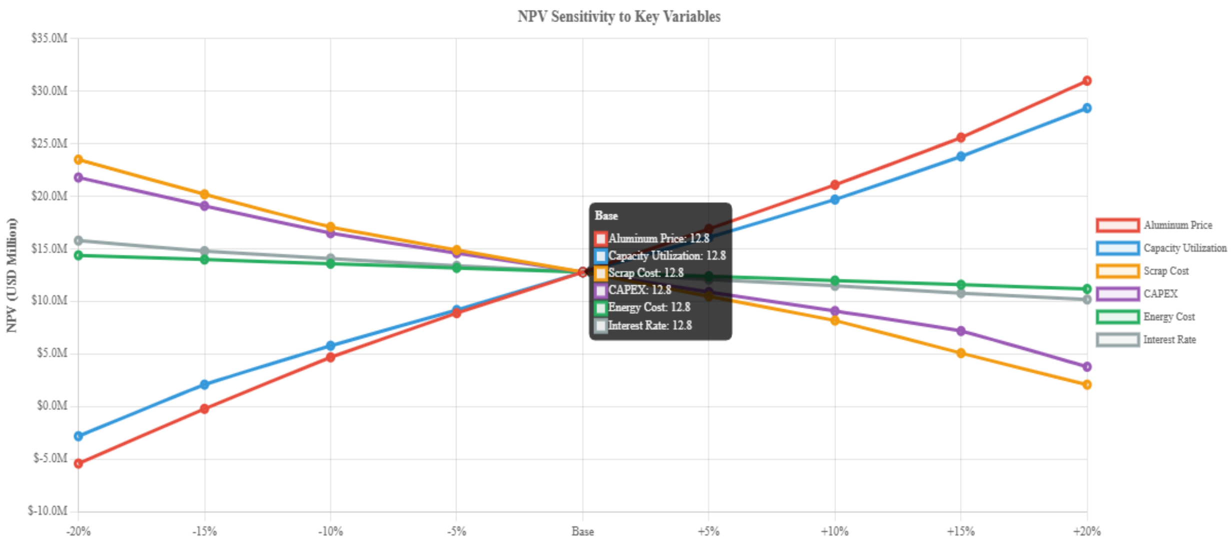

Figure 5. Sensitivity analysis showing BEP Analysis : Capacity vs Price

Sensitivity Analysis Interpretation:

The sensitivity analysis reveals that aluminum selling price has the highest impact on project NPV (sensitivity index = 0.89), followed by capacity utilization (0.77) and scrap cost (-0.52). A 10% increase in aluminum price increases NPV by USD 8.9 million, while a 10% decrease reduces NPV by USD 8.1 million. The project remains viable under most stress scenarios, with NPV turning negative only when aluminum prices fall below USD 1,950/ton or capacity utilization drops below 62%.

Table 6. Financial metrics summary and benchmarking

Financial Metric	Project Value	Industry Benchmark	Status
NPV (USD Million)	12.8	8-15	Favorable
IRR (%)	18.2	15-20	Above Average
Payback Period (years)	6.8	6-9	Competitive
DSCR (average)	2.1x	>1.5x	Strong
ROE (%)	24.7	18-25	Attractive

3.5 Project Impact and Strategies

3.5.1 Economic and Social Impact Analysis

The proposed aluminum ingot manufacturing plant will generate significant economic benefits for the local and national economy. Direct employment creation includes 150 full-time positions across production, maintenance, quality control, and administration functions. Indirect employment through supplier networks and service providers is estimated at 450 additional jobs following the economic impact [6]. Supply chain development will strengthen the aluminum recycling ecosystem in Indonesia, encouraging formalization of scrap collection networks and improving environmental management practices.

3.5.2 Environmental Impact and Sustainability

Water consumption optimization through closed-loop cooling systems and recycling reduces freshwater requirements by 40% compared to conventional designs. Wastewater treatment facilities ensure compliance with Indonesian environmental regulations following the methodology described by ISO 14040 standards 2006 [15].

Energy efficiency measures reduce specific energy consumption to 580 kWh/ton, significantly below industry averages following energy optimization principles [13]. Carbon footprint analysis shows 65% reduction in CO2 emissions compared to primary aluminum production, contributing to Indonesia's climate change mitigation goals

3.5.3 Technology Innovation and Competitive Advantages

The selected technology package incorporates latest innovations in aluminum recycling, providing competitive advantages through superior metal recovery, energy efficiency, and product quality. Electromagnetic stirring systems ensure homogeneous melt composition and reduce inclusion formation following technological advances [20]. Advanced process control systems utilize real-time composition analysis and automated parameter adjustment to maintain consistent product quality.

3.5.4 Investment Structure and Financing Strategy

The financing strategy balances debt and equity components to optimize capital costs while maintaining financial flexibility. The 60:40 debt-to-equity ratio aligns with Indonesian project finance market conditions and provides attractive returns for equity investors following financial structuring principles (2020) [16]. Local currency financing reduces foreign exchange risks while supporting domestic financial market development following risk management strategies [17]. Government incentive programs such as Tax holidays, accelerated depreciation, and infrastructure support reduce effective investment costs and improve project returns following economic development policies outlined by the Indonesian Ministry of Industry [1].

3.5.5 Quality Management and Product Standards

Comprehensive quality management systems ensure consistent product quality and customer satisfaction. Quality control procedures cover incoming raw materials, process parameters, and finished product specifications following international standards and best practices [12].

Customer qualification procedures ensure products meet application-specific requirements following certification principles described by ASTM standards 2020 [15].

3.5.6 Market Penetration and Customer Development Strategy

Market entry strategy focuses on establishing strong relationships with key customers in automotive, construction, and packaging sectors. Direct sales approach targets major aluminum consumers while distributor networks serve smaller customers following market development strategies.

Competitive positioning emphasizes quality consistency, supply reliability, competitive pricing, and customer service excellence. Local production advantages include reduced lead times, lower logistics costs, and flexible order quantities following competitive strategy principles [6]. Export market development targets ASEAN countries with growing aluminum demand and limited domestic production capacity. Regional trade agreements and logistics advantages support export competitiveness following international market development strategies [5].

3.6 Risk Assessment and Mitigation

Market risks include demand volatility, competitive pressure, and economic downturns. Mitigation strategies comprise diversified customer base, flexible production planning, and long-term supply contracts following risk management principles [37].

Operational risks encompass raw material supply disruption, equipment failures, and quality issues. Risk reduction measures include multiple supplier relationships, preventive maintenance programs, and comprehensive quality control systems. Financial risks include currency fluctuation, interest rate changes, and cost overruns. Mitigation approaches include local currency revenues, fixed-rate financing, and detailed cost control procedures. Regulatory risks are minimized through early permit acquisition and compliance with evolving environmental standards.

4. Conclusion

The feasibility study confirms strong commercial and technical viability for the proposed 50,000 TPY aluminum ingot manufacturing plant in Cilegon. Market analysis demonstrates robust demand growth averaging 8.5% annually, driven by expanding automotive and construction sectors. Raw material supply assessment indicates adequate aluminum scrap availability from domestic and regional sources.

Technology selection of reverberatory furnace with electromagnetic stirring provides optimal balance of metal recovery, energy efficiency, and operational flexibility. Financial analysis shows attractive returns with 18.2% IRR, 6.8-year payback, and positive NPV of USD 12.8 million, exceeding aluminum industry investment standards.

Strategic location in Cilegon Industrial Area provides competitive advantages through logistics efficiency, infrastructure availability, and market proximity. The project supports Indonesia's aluminum industry development while contributing to circular economy principles through scrap recycling.

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