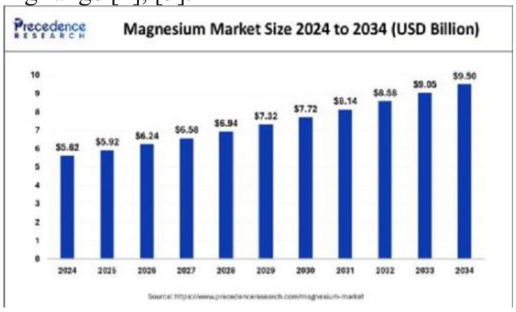
Techno-Economic Evaluation of Vertical Compound Retort Technology in Large-Scale Magnesium Production

Winny Wulandari[1],*, *Muhammad* Ilham Saputra[2], and *Rafindra* Andhika Permana[3], and *Azka* Anindya Aryasatya[4]
[1]Department of Chemical Engineering, Faculty of Industrial Technology, Bandung Institute of Technology, Indonesia 40132

Abstract. The rising global demand for lightweight structural materials has made magnesium vital in the automotive, aerospace, and electronics sectors. Currently, the Pidgeon process dominates magnesium production, particularly in China, but faces major drawbacks including high energy use, low efficiency, and labour-intensive operations. This study evaluates the technological and economic feasibility of Vertical Compound Retort (VCR) technology as a scalable alternative. Based on Pidgeon principles, VCR features a vertically oriented retort that enhances thermal efficiency, material throughput, and reduces labour intensity. Its design enables better heat distribution, easier material handling, and reduced heat loss and downtime. A feasibility study is conducted for a 3,000-ton/year plant in Gresik, East Java, Indonesia, which includes analysing process design, energy consumption, and material flow. The economic assessment covers capital and operating costs, profitability, and sensitivity analysis. Results indicate that VCR technology offers significant advantages in energy efficiency, process stability, and scalability. It holds promise for cost-effective, large-scale magnesium production in resource-rich regions.

1 Background

While the Pidgeon process is a well-established batch thermal process for magnesium production [1], with the push to decarbonization, there has been a recent paradigm shift in materials science and engineering, especially in the use and production of lightweight materials as a primary strategy to enhance energy efficiency. Magnesium (Mg) has emerged as a very promising material in this regard, as it is shown to enable significant sustainability advancements across key sectors. As the lightest of all structural metals, with a density that is 36% lower than Aluminium and 78% lower than that of iron by net volume, magnesium offers unparalleled potential for mass reduction in applications such as transportation [2]. This fundamental physical property of magnesium results in tangible performance benefits in transportation applications: a 10% reduction in a vehicle's weight can yield a 6 – 8% improvement in fuel efficiency for an internal combustion engine (ICE), while for electric vehicles, the same weight reduction typically translates to an approximate 13.7% increase in driving range [1], [3].



Source: https://www.precedenceresearch.com/magnesium-market

Fig. 1. Magnesium Market Size From 2024 – 2034 [2]

The strategic importance of magnesium is reflected in its robust market growth, with a 2021 valuation of USD 4.39 billion which is projected to expand at a 5.39% CAGR and reach as high as USD 9.50 billion by the early 2030s [2], [4]. This expansion is primarily driven by the automotive industry, which makes up 37.5% of the market, as manufacturers like Audi and Ford utilize magnesium to reduce vehicle weight, improve handling, and dampen vibrations [5], [6]. Beyond its use in transportation and aerospace for its high strength-to-weight ratio, magnesium unique properties like electromagnetic shielding and high thermal conductivity have led to its adoption in consumer electronics and also defense components [7], [8]. Furthermore, it is revolutionizing the biomedical field as a material for biodegradable orthopedic implants due to its elastic modulus of 45 GPa being similar to that of natural bone at 20 GPa, as compared to traditional metals such as titanium with 100 GPa [9].

Geographically, magnesium production and consumption are centred around the Asia-Pacific region, which commanded over 45% of the market's revenues share in 2021 and is forecasted to continue its rapid growth [4]. This is mostly fuelled by the burgeoning automotive and industrial sectors in China and India, which play the region's central role in the future of the global magnesium supply chain. The immense potential of magnesium to enable sustainability in these downstream industries, however, is heavily reliant on the fact that the metal itself can be sustainably produced. This creates a critical dependency: the "green" credentials of the next generation of vehicles and aircraft are heavily linked to the environmental performance of

---

* Corresponding author: winnywulandari@itb.ac.id

the upstream processes used to manufacture this lightweight material.

Currently, the global magnesium industry is dominated by the Pidgeon process, a silicothermic reduction method that accounts for over 85% of the world’s primary magnesium supply [10]. The dominance of this production method is mostly concentrated in China, which has leveraged the process’s relatively low capital investment and technological simplicity to become the world’s leading producer. However, the environmental cost of this method is staggering, as it is characterized by high energy consumption, requiring a gross energy input of 171 – 261 GJ for every tonne of magnesium produced, which roughly translates to 6 to 9 tonnes of coal equivalent (tce) [11]. Furthermore, the Pidgeon process also emits 21.8 – 47 kg of $CO_{2(eq)}$ per kg of magnesium produced, which is an immense carbon footprint due to its batch-wise, intermittent nature involving cooling between calcination and reduction that leads to substantial thermal energy losses [10]. Other methods of magnesium production also have their issues, such as molten salt electrolysis of anhydrous magnesium chloride, which reduces the GHG emissions as low as 5.3 – 8.5 kg $CO_{2(eq)}$ per kg of magnesium produced but faces its own issues with the production of toxic chlorine and a high electricity consumption of 10.5 – 14 kWh per kg of magnesium [12].

Building upon the limitations of both the Pidgeon process and conventional vertical retort methods, the compound-vertical retort (VCR) magnesium production technology represents a significant advancement in the field. This technology addresses issues such as slag adhesion, short retort lifespan, and inefficient thermal management. The VCR process introduces innovations such as a ceramic-lined steel retort, improved thermal control and a sectional crystallizer that enhances the purity of the magnesium crown [13]. These changes lead to a substantial increase in productivity, such as an increased magnesium yield per retort by 4 – 5 times and extending retort life to over 180 days, which in combination with an energy consumption reduction by over 20%. Furthermore, VCR technology allows us to eliminate manual slag handling and mitigate high emissions and workplace hazards that are typical of normal Pidgeon processes. These advancements allow magnesium to be produced in a cleaner, more efficient way, while being economically competitive as compared to methods such as electrolysis.

In this techno-economic evaluation, we will be exploring the feasibility of implementing VCR technology for magnesium production in Indonesia, with a specific focus on the Gresik Region. Given Indonesia’s growing industrial demand and Gresik’s strategic position with access to essential infrastructure and resources, this study aims to assess whether VCR technology can offer an economically viable alternative to traditional magnesium production methods within the local context. The evaluation will consider factors such as resource availability, and total costs to use this technology.

2 Process Flow Diagram

The Pidgeon process is a well-established batch thermal reduction method to produce magnesium metal from dolomite ores. Historically, this process was developed in the early 1940s by the Canadian chemist Lloyd Montgomery Pidgeon. The magnesium production process begins with the careful handling, preparation, and transfer of raw materials using bucket elevators, screw conveyors, and scraper conveyors to ensure seamless movement. Ferrosilicon is first reduced to the required particle size in a jaw crusher, while fluorite and calcined dolomite are supplied in a smaller particle size. Critically, the addition of fluorite (CaF_2) serves as a catalyst: it acts as a mineralizer that lowers the activation energy of the reduction reaction and also facilitates the crystallization of the silicate by-product, which enhances reaction kinetics [14]. The combined mixture of calcined dolomite, ferrosilicon, and fluorite is then milled in a ball mill to produce a 120-mesh mixed powder, which is subsequently briquetted in the briquetting machine. At the core of the operation is the reduction furnace, where the briquetted material undergoes a high temperature reduction reaction as follows:

$$2MgO_{(s)} + 2CaO_{(s)} + Si_{(s)} = 2Mg_{(g)} + Ca_2SiO_4 \quad (1)$$

The process also integrates equipment to control emissions such as bag filters. The refining stage follows, where the final magnesium product is purified and byproducts such as slag are appropriately handled, ensuring the overall process meets both operational and environmental standards.

Within this process, the operating conditions of most equipment’s are ambient temperature and pressure as they are mechanical equipment’s such as the conveyors, mills, bucket elevators and briquetting machine. However, one piece of equipment that does not follow this is the reduction furnace, the of operating conditions of this equipment at 1250 °C and 10 Pa, the heat is provided by coal, this is based on research on the operating conditions of a retort furnace and its effect to the magnesium recovery rate in the Mg crown, with the operating conditions around 1200 – 1300 °C reaching 90% magnesium recovery rate [15].

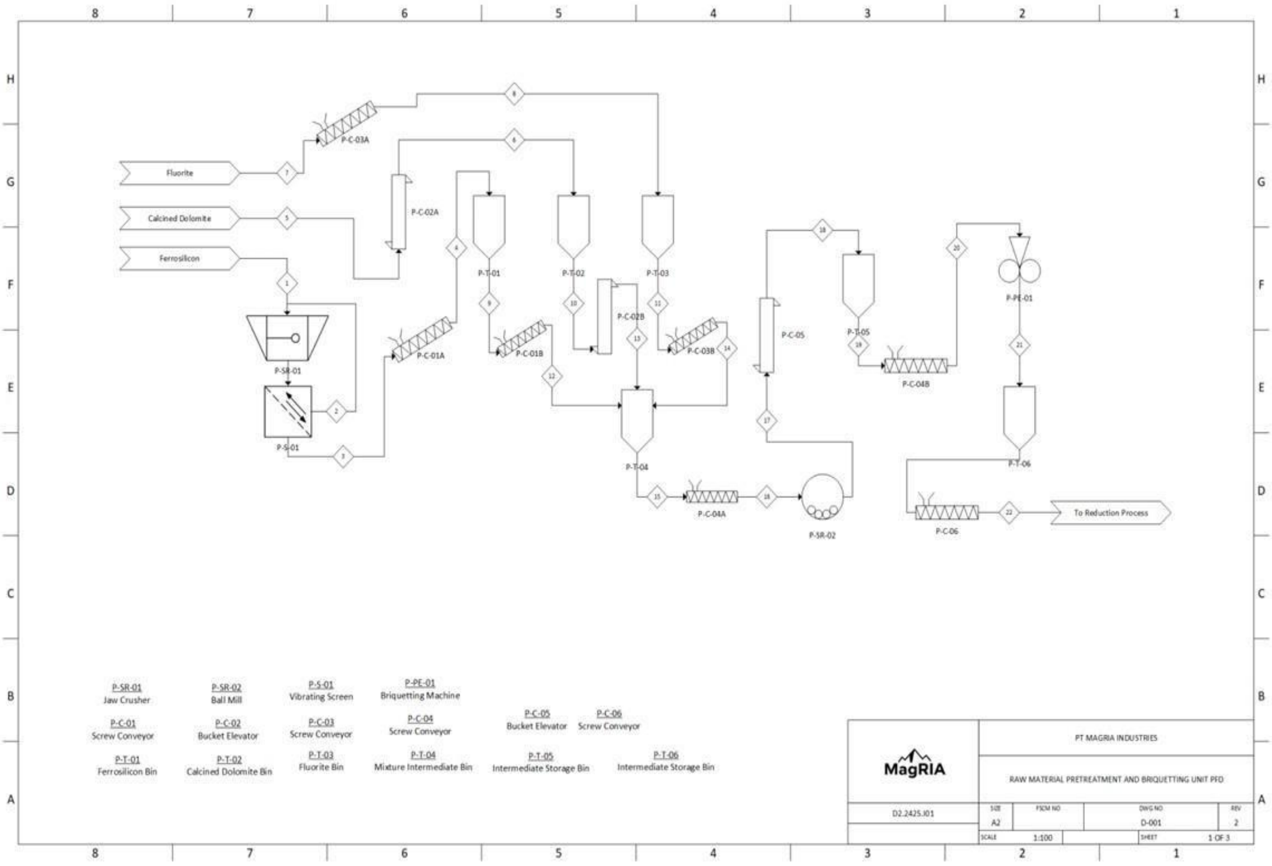


Fig. 2. Raw Materials and Pretreatment Process Flow Diagram

Within the same piece of equipment, there is a cooler part of the retort operating at 625 °C and 10 Pa, which is cooled by water, this temperature is to ensure that most of the magnesium becomes solid crown. Equipment operating under vacuum conditions, where the vacuum outlet is in the cooler part of the retort, so the magnesium vapor moves from the hotter part of the retort to the cooler part.

3 Sizing and Process Equipment Cost

The equipment process of the magnesium production plant is divided into three sections, which are raw materials preparation and briquetting, magnesium reduction, and magnesium refining equipment. The reference used to calculate the purchase cost and bare module cost of each equipment are using a book of Analysis, Synthesis, and Design of Chemical Process (Turton 5th Ed, 2018) and Aspen Economic Process Analyzer

Table 1. Process Equipment Specification and Price

Name	Qty	Specification	Price (US$)
Pretreatment and Raw Material Section			
Jaw Crusher	1	Jaw Size: 254 x 152 mm	319,257.02
Screw Conveyor 01	2	Screw Diameter: 9inch, Length: 45 feet, Inclination: 25^o	33,266.90
Bucker Elevator 01	2	Height: 46 feet, Capacity: 590 ft^3/h	23,472.49
Screw Conveyor 02	2	Screw Diameter: 6inch, Length: 34 feet, Inclination: 25^o	25,167.13
Screw Conveyor 03	2	Screw Diameter: 12inch, Length: 32.8 feet, Inclination: 0^o	40,788.11
Bucket Elevator 02	2	Height: 46 feet, Capacity: 590 ft^3/hr	23,472.49
Screw Conveyor 04	1	Screw Diameter: 12inch, Length: 34 feet, Inclination: 0^o	20,394.05
Ball Mill	1	Diameter: 2.1 m, Length: 3.0 m	72,000.00

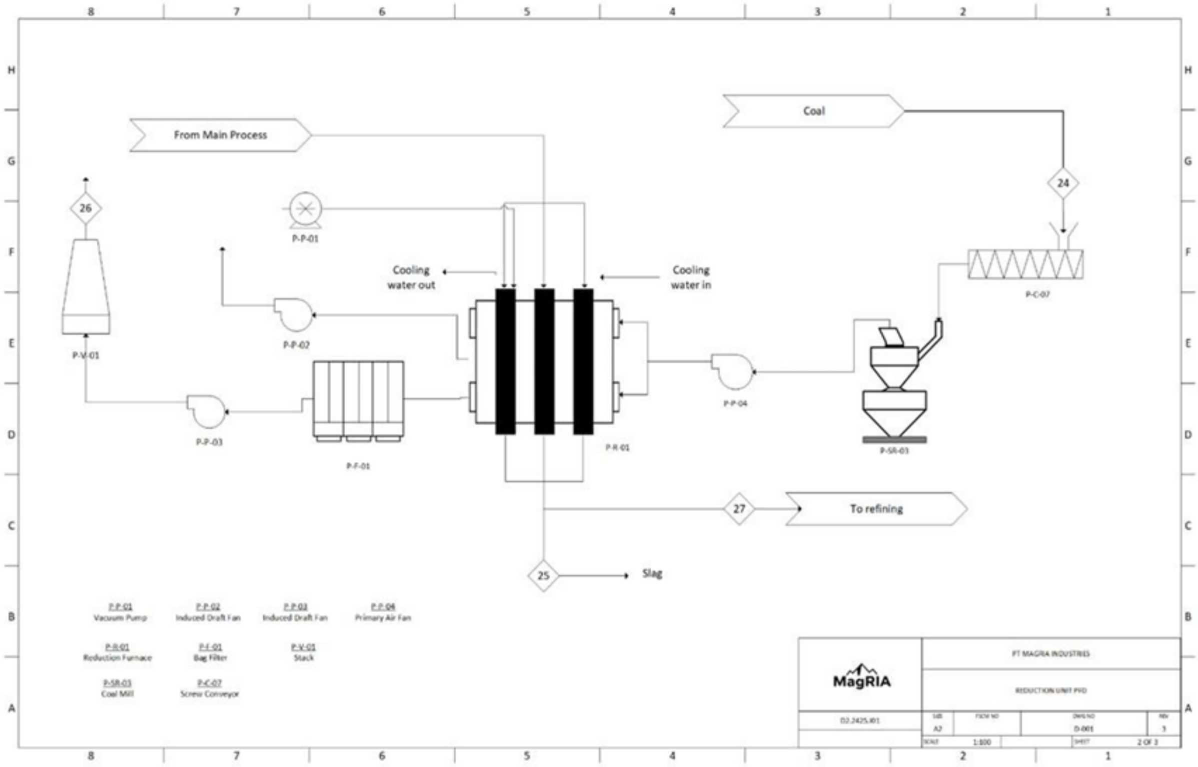


Fig. 3. Magnesium Reduction Process Flow Diagram

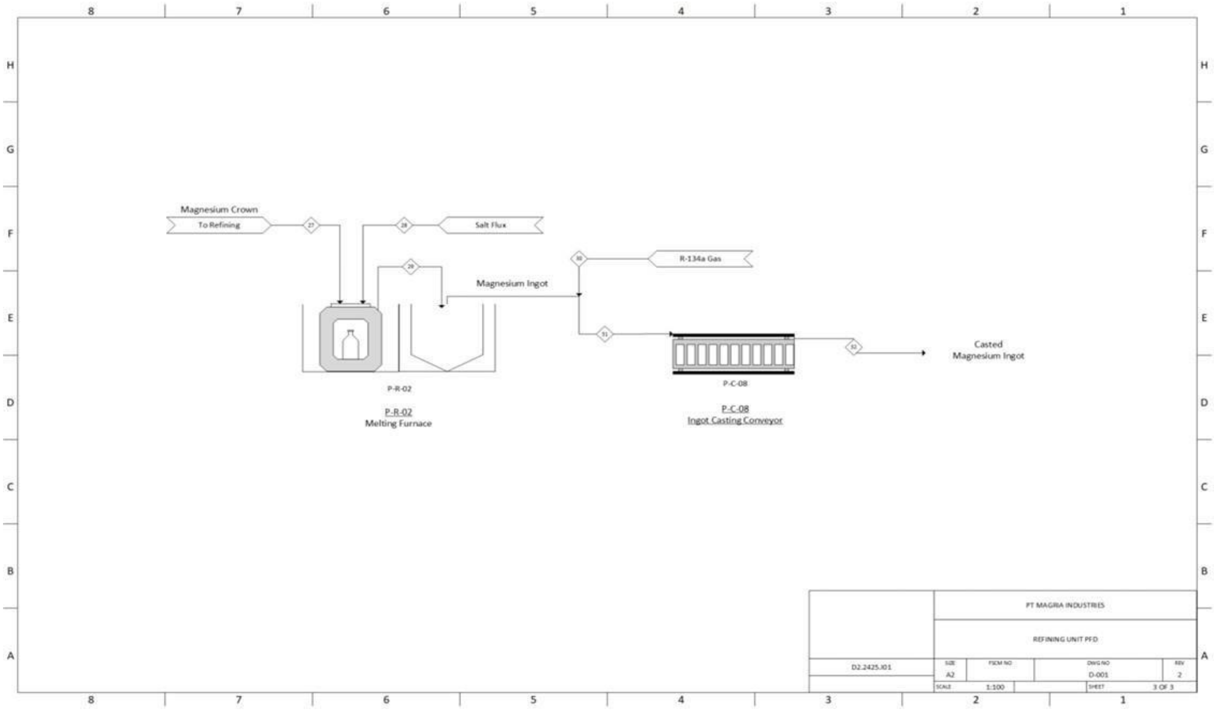


Fig. 4. Magnesium Refining Process Flow Diagram

Table 1. Process Equipment Specification and Price

(Continued)

Name	Qty	Specification	Price (US$)
Pretreatment and Raw Material Section			
Briquetting Machine	2	Roller diameter: 758 mm, width of surface: 225 mm, pellet diameter: 22 mm	73,309.65
Vibrating Screen	1	Length: 2500 mm, Width: 500 mm	7,360.00
Ferrosilicon Silo	1	Capacity: 25.2 m^3, Total Height: 6.45, Diameter: 2.75 m	26,717.86
Calcined Dolomite Silo	1	Capacity: 352 m^3, Total Height: 13.75 m, Diameter: 6.8 m	129,983.12
Calcium Fluoride Silo	1	Capacity: 10 m^3, Total Height: 4.60, Diameter: 2.00 m	15,252.55
Mixture Silo	1	Capacity: 415 m^3, Total Height: 6.8, Diameter: 15.5 m	143,479.62
Storage Silo	1	Capacity: 415 m^3, Total Height: 6.8, Diameter: 15.5 m	143,479.62
Pellet Silo	1	Capacity: 415 m^3, Total Height: 6.8, Diameter: 15.5 m	143,479.62
Magnesium Reduction Section			
Reduction Furnace	4	Furnace: 12 x 6 x 6 m	4,815,832.28
Name	**Qty**	**Specification**	**Price (US$)**
Vacuum Pump	8	Driver Type: Shaft seal; Suction Pressure: 1.02 kg/cm^{2}g; Discharge Pressure: 0.00 kg/cm^{2}g; NPSH: 19.82 m	179,846.37
Bag Filter	2	Inlet Dust Concentration: 0.598 g/m^3; Filter Area: 41.59 m^2; Bag Area: 1.884 m^2; Number of Bags: 23	129,364.84
Induced Draft Fan	2	Suction Pressure: 0.9 Pa; Discharge Pressure: 1 atm; Driver: Electrical Motor; Flowrate: 363.6 kg/hr	17,459.92
Magnesium Refining Section			
Melting Furnace	8	Melting Capacity: 250 kg/hr; Working T: 850°C; Weight: 1415 kg; Length: 2450 mm; Width: 1190 mm; Height: 1000 m	847,175.30
Name	**Qty**	**Specification**	**Price (US$)**
		Retort **Crystallizer**: Height: 0.6 m, Inner Diameter: 0.5 m, Central Inner Diameter: 0.24 m Magnesium Vapor Aperture: 0.01 m **Main Retort**: Inner Radius: 0.06 m Outer Radius: 0.2 m Height: 6 m	
Vertical Roller Mill	1	Efficiency: 95%; Grinding area: 0.1797 m^2; Height: 5 m; Weight: 265.07 kg	23,142.19
Primary Air Fan	1	Suction Pressure: 1 kg/cm2 g; Discharge Pressure: 2 kg/cm^2 g; Driver: Electrical Motor; Flowrate: 424.24 kg/hr	14,463.87
Induced Draft Fan	8	Suction Pressure: 10 Pa; Discharge Pressure: 1 atm; Driver: Electrical Motor; Flowrate: 3107.6 kg/hr	69,426.57
Coal Conveyor	1	Screw Diameter: 4 inches; Length: 45 feet; Inclination: 25$_o$	15,786.89
Casting Conveyor	1	Number of Mould: 150; Ingot Weight: 6 kg; Conveyor Speed: 2.5 M/min; Inclined Angle: 10°; Length Conveyor: 2.70 m	29,000.00

4 Economic Calculation

Most of the economic evaluation was based on an input-output model, visualized in Fig. 5 below, where the main revenue consists of magnesium ingot and solid slag sales. The profitability analysis includes the determination of net present value, cumulative cash position, internal rate of return, return on investment, and payback period. Furthermore, a sensitivity analysis was also conducted to determine the most critical economic factor of our magnesium plant. The basis of evaluation and calculation follows the Analysis, Synthesis, and Design of Chemical Processes by Turton *et al.* (2013).

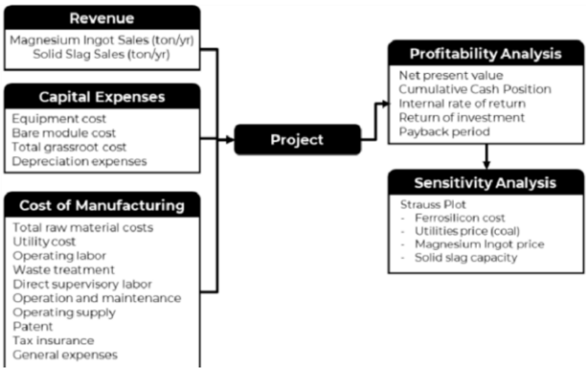


Fig. 5. Input and Output Model

The economic feasibility is grounded in well researched, realistic assumptions, which include key parameters such as a CEPCI index of 799.2 as of June 2025, land and salary benchmarks based on Gresik Industrial Estate data, and a conservative financial structure with a 1:1 debt-to-equity ratio and a 5.5% interest rate, as per Bank Indonesia. These assumptions, summarized in Table 2 below, reflect the typical conditions of industrial projects in East Java and align with national policies and industrial norms.

Table 2. Plant Economic Assumptions

No.	**Parameter**	**Assumption**	**Additional Information**
1	Plant operation	330 days/year	
2	CEPCI	799.2	CEPCI June 2025
3	Equipment cost basis	397	CEPCI 2004
4	Operator salary	\$450/month \$600/month	1.5 and 2 times Regional Minimum Wage (UMR) of Gresik (2025)
5	Land cost	\$197/m^2	Manyar, Gresik Industrial Estate land cost
6	Plant Area	27,500 m^2	
7	Working Capital	15% of FCI	Based on Turton et al., 2013 and the small scale of the plant
8	Plant salvage value	10%	Assumption
9	Income tax rate	20%	UU No. 36 Tahun 2008
10	Debt to equity ratio (DER)	1:1	Common DER of smelting plants
11	Interest rate	5.50%	BI rate as of June 2025
12	Loan	5 years	
13	Repayment Depreciation method	Straight line method	UU No. 36 Tahun 2008
14	Depreciation duration	16 years	UU No. 36 Tahun 2008
15	WACC	7%	Average WACC of magnesium production plant
16	MARR	8%	WACC + Risk free rate of 1%
17	Construction period	1 year	Small scale plant
18	Magnesium Ingot Price	\$2600/ton	Slightly higher than the FOB Magnesium pricing traded in China

The total capital investment required is estimated at 36.6 million US Dollars, which is broken down into: 16.7 million US Dollars for total bare module cost, 4.4 million US Dollars for land acquisition with an area of 27,500 m^2, and 4.2 million US Dollars for working capital. The total bare module cost, explained in previous sections, is further split into 4 different sections, with the magnesium reduction unit costing the most at 14.3 million US Dollars. This capital supports the development of a lean, efficient facility that can scale as market demand increases. The total capital investment is visualized in Fig. 6 below.

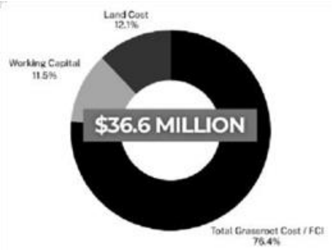


Fig. 6. Capital Investment Break Down

The total operating expenditure is 7.9 million US Dollars, which can be broken down into direct manufacturing cost, fixed manufacturing cost, and general expenses, with direct manufacturing cost contributing the most at 78.7%. This can be further broken down, where it can be seen, in Fig. 7 below, that raw materials make up the bulk, with Ferrosilicon alone accounting for almost 3 million US Dollars annually. The utility use consists of electricity costing 575,000 US Dollars and coal costing 305,000 US Dollars annually. The plant is designed to produce 3,000 tons of high-purity magnesium ingots annually priced at 2600 US Dollars per ton, along with 26,450 tons of solid slag byproduct per year sold at 180 US Dollars per ton. With these streams, projected annual revenue reaches 12.56 million US Dollars.

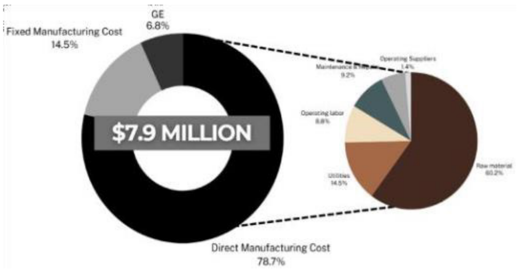


Fig. 7. Operational Expenditure Break Down

Table 3. Raw materials breakdown

No	Material	Requirement (ton/year)	Utility Cost (US$/ton)	Annual Cost (US$)
1	Calcined Dolomite	25,221	6.2	156,368.77
2	Ferrosilicon	3,210	924.93	2,969,025.30
3	CaF_2	1,270.5	359.7	457,000.80
4	$MgCl_2$	117.6	192.7	22,660.79
5	KCl	64.8	436.8	28,302.86
6	BaCl	48.0	1,089.4	52,289.38

5 Cashflow Analysis

The project's feasibility was evaluated based on both non-discounted and discounted economic indicators from the plant's projected cash flows, as summarized in Table 3. On a non-discounted basis, the plant achieves a cumulative cash position of over USD 81.7 million and a capital coverage ratio of 3.42, demonstrating ample capacity to service its debt. The payback period is 3.8 years, well within the assumed plant lifespan, and the return on investment is a satisfying 33.8 %. The cashflow is presented in Fig. 8 below.

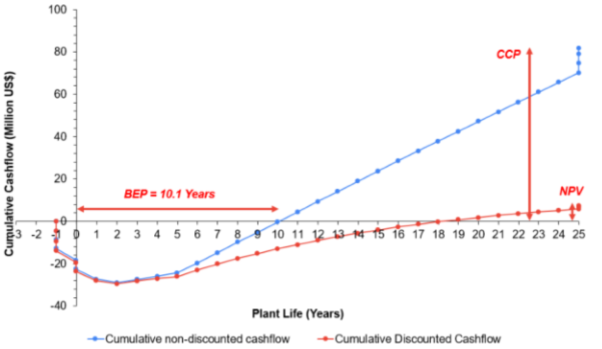


Fig. 8. Cashflow Presentation

When we introduce the time value of money, however, the picture changes. Although the net present value remains slightly positive, the discounted payback period extends to 11.9 years, and the internal rate of return falls to 8.71%. Assuming the industry's minimum acceptable rate of return is 8%, an IRR slightly above that threshold means the project barely meets the financial attractiveness criterion. This shortfall stems largely from high raw-material costs because Indonesia must import ferrosilicon at a premium, which compresses margins over the plant's operational life. The next section, therefore, examines how variations in key parameters such as ferrosilicon price and product price would affect these discounted indicators.

Future scenarios could further enhance the plant's profitability. These may include an expansion of plant capacity, an increase in the market price of magnesium ingots and solid slags, or improvements in utility efficiency and raw material prices. Such developments could reduce the Cost of Manufacturing (COM), increase revenue, and strengthen the overall financial position of this industry.

6 Sensitivity Analysis

The sensitivity analysis conducted as a part of this techno-economic evaluation provides a comprehensive view of how various economic variables that affects this VCR technology-based magnesium production influences key profitability indicators such as Net Present Value (NPV), internal rate of return (IRR), Return on Investment (ROI), Payback Period (PBP), Discounted payback period (DPBP), and cumulative cash position (CCP). Among all the factors considered, the selling price of magnesium ingot stands as the most influential variable by a considerable margin. A 25% increase in selling price, for instance, results in a significant rise in both NPV and IRR, with NPV alone surging to above 500%, whereas a corresponding decrease sends all profitability indicators sharply into negative territory. This, in turn, strongly highlights how the project's high sensitivity to market pricing and the paramount importance of price stabilisation. Similarly, the ability to effectively commercialise slag by-products plays a crucial secondary role. As slag selling capacity decreases by modest margins, there is a steep decline in CCP and DPBP, clearly indicating that slag valorisation is not merely supplementary, but is also considered to be integral to the overall economic viability of the VCR based production system.

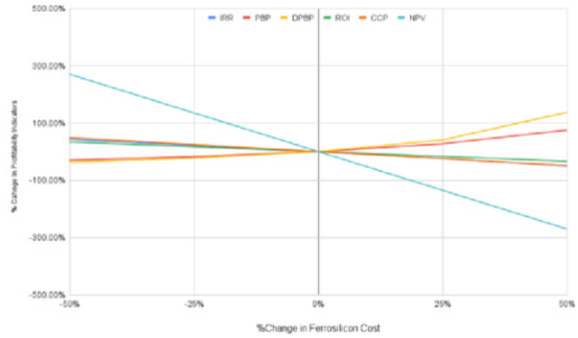


Fig. 9. Strauss Plot of Ferrosilicon Cost against Profitability Indicators

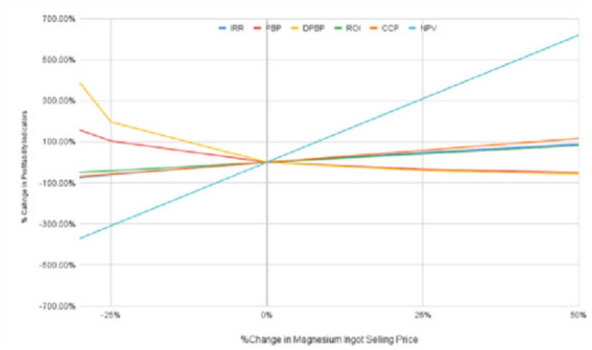


Fig. 10. Strauss Plot of Magnesium Ingot Selling Price against Profitability Indicators

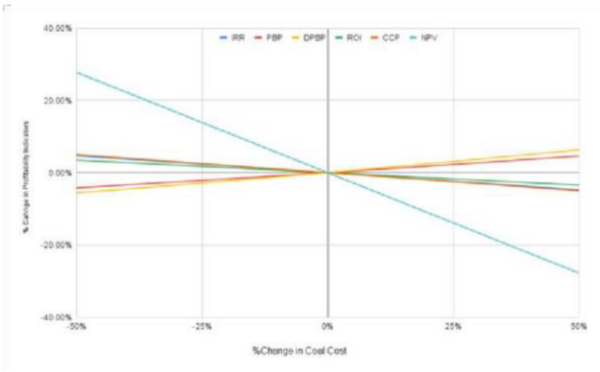


Fig. 11. Strauss Plot of Coal Cost against Profitability Indicators

In contrast, input costs, which are coal and ferrosilicon, exhibited a more balanced, albeit still impactful, influence on overall project profitability. Fluctuations in ferrosilicon cost, for example, have a noticeable effect on NPV and IRR, which reflects the catalyst-intensive nature of the silicothermic reduction process. Meanwhile, coal costs show a relatively symmetric and less volatile pattern across all metrics, hence showing that there is a degree of resilience in the thermal energy supply chain. Taken together, these findings show that the VCR technology demonstrates robust financial performance under small to moderate raw material cost variations; however, it remains vulnerable to shifts in magnesium market prices and by-product utilisation strategies. As such for industrial scale deployment, especially in developing but resource-rich regions in Indonesia, such as Gresik, comprehensive risk management strategies, including fixed-price off-take agreements and investment in slag-based product developed, will be essential to ensuring long-term economic and environmental sustainability.

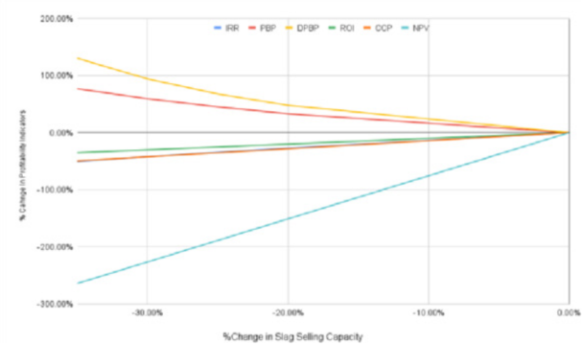


Fig. 12. Strauss Plot of Slag Selling Capacity against Profitability Indicators

7 Conclusion

This paper proposes a Pidgeon process magnesium plant operating 330 days per year to produce 3,000 tonnes of magnesium ingots and 26,450 tonnes of slag annually. The project requires a one-to-one debt-to-equity capital structure totalling US$36.61 million, comprising US$27.98 million in fixed capital, US$4.20 million in working capital, and US$4.43 million for land. Annual raw material costs are estimated at US$3.13 to US$3.69 million, with total manufacturing costs of US$7.9 million and projected revenues of US$12.57 million.

Over its 25-year life, the project generates a cumulative cash position of US$81.68 million, a payback period of 3.8 years, a non-discounted return on investment of 33.8%, and a positive net present value of US$7.46 million. The internal rate of return of 8.71% slightly exceeds the minimum acceptable rate of return of 8%, indicating marginal viability on a discounted basis. Sensitivity analysis identifies magnesium ingot price and ferrosilicon cost as the primary profitability drivers, while coal utility costs and slag sales have limited impact, and despite financial constraints, the plant is recommended as a strategic basis for developing domestic magnesium production and a future industrial park in Indonesia.

References

1. S. Lee, “Magnesium Alloys in Automotive Industry,” 2025. [Online]. Available: https://www.numberanalytics.com/blog/ultimate-guide-magnesium-alloys-automotiveapplications

2. Precedence Research, “Magnesium Market Size to Hit USD 9.05 Billion by 2033,” Jul. 2024, *Precedence Research* . [Online]. Available: https://www.precedenceresearch.com/magnesium-market

3. F. Czerwinski, “Current Trends in Automotive Lightweighting Strategies and Materials,” *Materials*, **14**, no. 21, p. 6631, Nov. 2021, doi: https://doi.org/10.3390/ma14216631

4. GVR, “Metal Magnesium Market Size Report, 2022-

2030," 2021. [Online]. Available: https://www.grandviewresearch.com/industryanalysis/metal-magnesium-market

5. BSI, "Magnesium Market Size, Share, Trend Report, 2033," 2025. [Online]. Available: https://www.businessresearchinsights.com/market-reports/magnesium-market-119223

6. IMA, "Automotive Applications - International Magnesium Association," 2025. [Online]. Available: https://www.intlmag.org/page/app_automotive_ima

7. S. V. S. Prasad, S. B. Prasad, K. Verma, R. K. Mishra, V. Kumar, and S. Singh, "The role and significance of Magnesium in modern day research-A review," *Journal of Magnesium and Alloys*, **10**, Jul. 2021, doi: https://doi.org/10.1016/j.jma.2021.05.012

8. B. Landkof, "Magnesium Applications in Aerospace and Electronic Industries," *Magnesium Alloys and their Applications*, pp. 168 – 172, Jul. 2006, doi: https://doi.org/10.1002/3527607552.ch28

9. L. Prawin Babu and R. Radha, "Advancements in magnesium-based alloys for orthopedic implants: balancing corrosion, mechanical properties, and biological effects *(part 1)* – a review," *Canadian Metallurgical Quarterly*, pp. 1 – 26, Jul. 2024, doi: https://doi.org/10.1080/00084433.2024.2427455

10. H.-J. Jeoung, T.-H. Lee, K.-W. Yi, and J. Kang, "Review on Electrolytic Processes for Magnesium Metal Production: Industrial and Innovative Processes," *Mater Trans*, **66**, pp. 823 – 839, Jul. 2025, doi: https://doi.org/10.2320/matertrans.mt-mb2024014.

11. J. Xu, T. Zhang, and X. Li, "Research on the Process, Energy Consumption and Carbon Emissions of Different Magnesium Refining Processes," Materials, **16**, p. 3340, Mar. 2023, doi: https://doi.org/10.3390/ma16093340.

12. M. S. Choi, C. K. Lee, G. G. Lee, S. K. Cho, and J. Y. Jung, "Technology of Molten Salt Electrolysis of Magnesium Chloride," Materials science forum, vol. **654 – 656**, pp. 799 – 802, Jul. 2010, doi: https://doi.org/10.4028/www.scientific.net/msf.654-656.799.

13. R. Li, S. Zhang, P. Yang, J. Liu, and F. Liu, "Research, development and application of compound-vertical-retort technology for magnesium production," Journal of Magnesium and Alloys, **11**, no. 12, pp.4724 – 4736, Dec. 2023, doi: https://doi.org/10.1016/j.jma.2023.05.013.

14. J.-H. Guo, D.-X. Fu, J.-B. Han, Z.-H. Ji, Y.-S. Wang, and T.-A. Zhang, "The effect of calcium fluoride on extracting magnesium from magnesite and calcium carbonate by silicothermal reduction in flowing argon," *Journal of mining and metallurgy. Section B, Metallurgy*, **58**, no. 1, pp. 19 – 28, Jan. 2022, doi: https://doi.org/10.2298/jmmb210318045g.

15. O. Yucel, S. Yiğit, and B. Derin, "Production of magnesium metal from Turkish calcined dolomite using vacuum silicothermic reduction method," in Materials Science Forum, *Trans Tech Publ*, 2005, pp. 39 – 42.