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TECHNO-ECONOMIC OF GRAPHITE ANODE RECYCLING PROCESS OF ELECTRIC VEHICLE LITHIUM-ION BATTERIES

TEKNO EKONOMI PROSES DAUR ULANG ANODA GRAFIT BATERAI LITHIUM-ION KENDARAAN LISTRIK

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ABSTRACT

Graphite is the primary material for battery anodes used in electronic devices such as cell phones, laptops, and electric vehicles. Exploiting natural graphite in Indonesia is still in the exploration stage. The ever increasing demand for energy storage devices poses challenges in producing battery-grade graphite. One possible approach is to recycle the graphite anode (AG) from used Lithium-ion Batteries (LIB) into battery components. By utilizing waste as a raw material, production costs are lower as well as the use of LIB becomes more sustainable. This study discusses the techno-economics of AG recycling from electric vehicle (EV) LIBs. Secondary data is used from various research reports, journals, and books published through the official website as references and assumptions in calculations and analysis. Mechanical separation to remove plastic components, washing with organic solvents (using dimethyl carbonate-DMC) and using dimethyl carbonate (DMC) and N-methyl-2-pyrrolidone (NMP), then washing process with H_2SO_4 + H_2O_2 purifies graphite to be reused as anode material for the new LIB. Economic analysis shows that the Net Present Value is IDR 388,675,699, the Internal Rate of Return is 33.79% per year, and the Payback Period is two years and ten months. These three indicators show that the project is financially viable. The sensitivity analysis shows that it is still profitable if there is an increase in production costs of up to 20% and a decrease in selling prices of up to 20% or USD 12,000 per tonne.

Keywords: lithium-ion batteries, electric vehicle, graphite anode recycle, economic.

ABSTRAK

Grafit merupakan bahan utama anoda baterai yang digunakan pada perangkat elektronik seperti ponsel, laptop, dan kendaraan listrik. Pemanfaatan grafit alam di Indonesia masih dalam tahap eksplorasi. Permintaan perangkat penyimpanan energi yang semakin meningkat menimbulkan tantangan dalam memproduksi grafit tingkat baterai. Salah satu pendekatan yang mungkin dilakukan adalah dengan mendaur ulang anoda grafit (AG) dari Baterai Lithium-ion (LIB) bekas menjadi komponen baterai. Dengan memanfaatkan limbah sebagai bahan baku, biaya produksi menjadi lebih rendah serta penggunaan LIB menjadi lebih berkelanjutan. Penelitian ini membahas tentang tekno-ekonomi daur ulang AG dari LIB kendaraan listrik (EV). Data sekunder digunakan dari berbagai laporan penelitian, jurnal, dan buku yang diterbitkan melalui situs resmi sebagai referensi dan asumsi dalam perhitungan dan analisis. Pemisahan mekanis untuk menghilangkan komponen plastik, pencucian dengan pelarut organik (menggunakan dimetil karbonat-DMC) dan menggunakan dimetil karbonat (DMC) dan N-metil-2-pirolidon (NMP), kemudian proses pencucian dengan H_2SO_4 + H_2O_2 *memurnikan grafit untuk digunakan kembali sebagai bahan anoda untuk LIB baru. Analisis ekonomi menunjukkan Net Present Value sebesar Rp388.675.699, Internal Rate of Return sebesar 33,79% per tahun, dan Payback Period dua tahun sepuluh bulan. Ketiga indikator ini menunjukkan bahwa proyek ini layak secara finansial. Analisis sensitivitas menunjukkan masih menguntungkan jika terjadi kenaikan biaya produksi hingga 20% dan penurunan harga jual hingga 20% atau USD 12.000 per ton.*

Kata kunci: baterai lithium-ion, kendaraan listrik, daur ulang anoda grafit, ekonomi.

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INTRODUCTION

Lithium-ion batteries (LIB) are an essential part of life as a power source for electric vehicles, smartphones, laptops, and other electronic devices (Kang *et al.*, 2020). LIB has many advantages by presenting the unparalleled combination of high energy and power density, long cycle life, reusable energy power, and low pollutant emission so that the LIB will become the dominating technology for power sources in transportation and consumer electronics (Autthawong *et al.*, 2022; Qian *et al.*, 2022). The shift in technology from fossil energy to electrical energy has many implications apart from reducing pollution and using alternative energy sources.

Electric vehicles (EV) as an alternative to internal combustion engine vehicles (ICEV) (Rallo *et al.*, 2020). Since 2016, there has been a significant increase in global use, ranging from plug-in hybrid electric vehicles (PHEV) to battery-powered vehicles (BEV). In 2017, sales exceeded 3.1 million units; in 2021, EVs used worldwide reached 16.4 million units (Triaswinanti *et al.*, 2023). China will be the largest market for the EVs by 2022, accounting for 59% of the total global sales. China is not only a market but is also a significant producer. About 6.7 million (64%) of EVs were sold in expected to be manufactured in China. Meanwhile, Tesla will be the company with the highest revenue in 2022, increasing the LIB production. According to data Statista (2023), the LIB sales for EVs and PHEVs are expected to increase from 0.77 million in 2016 to 17.07 million in 2028 (Figure 1). Meanwhile, according to Gao *et al.* (2018) in (Mossali *et al.*, 2020), 2045 of them is estimated to reach 180 million.

Increased sales of PHEVs and BEVs will generate large amounts of LIB waste when batteries end their useful life (Moore, Arefin and Rosenfeld, 2018; Nguyen-Tien *et al.*, 2022). In 2025, it is estimated that 250 thousand tons of LIB will expire (Shahjalal *et al.*, 2022), meaning that vehicle LIB can no longer be used and becomes waste, while the disposal of LIB waste has the potential to impact the environment, but LIB waste also contains valuable materials that can be reused. Therefore the reuse and recycling of batteries is an urgent priority worldwide (Zhao *et al.*, 2021). Many countries have worked to manage LIB waste (Zhang *et al.*, 2018). In 2018, over 68% of LIB recycling was held in China, around 19% in South Korea, and less than 5% in the European Union (Samarukha, 2020). While the recycling and reusing anode materials have received less attention (Liu *et al.*, 2020) but with the rapid increase in the use of LIB, effectively recycled anode materials are also believed to provide significant savings (Ni'mah *et al.*, 2022).

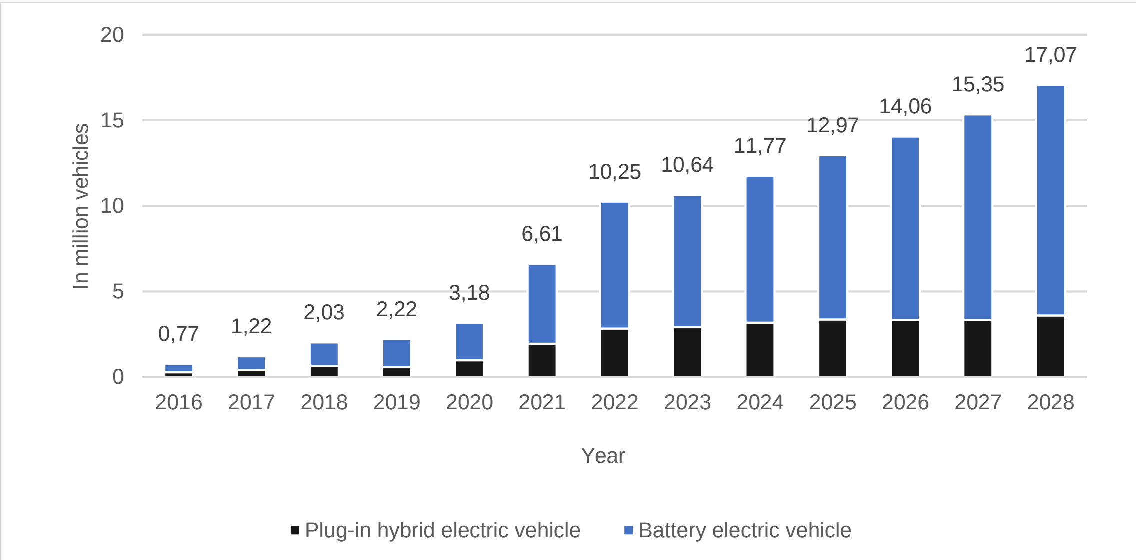

Figure 1. Vehicle sales and forecast up to 2028 (Statista, 2023)

LIB consists of a cathode which serves as a positive electrode, and an anode as a negative electrode. The anode is a negative electrode that acts as a place for oxidation reactions and the initial gathering of lithium ions before use. The amount of lithium ions that gather at the anode can determine the capacity of a battery (Winslow, Laux and Townsend, 2018). The anode is an active material connected by a conducting copper sheet. The materials for the manufacture of the anodes consist of active materials, binders, additives (carbon black), and solvents. The carbon black is used to increase the electrical conductivity between the active materials (Fransson *et al.*, 2001). The binder functions as a binder between the active and conductive materials in the anode. The oxidation reaction at the anode is associated with releasing lithium ions or discharge. Some components in the LIB, such as the negative electrode (anode), a positive electrode (cathode), an electrolyte (as a conductor), and a separator, will prevent short circuits) Figure 2.

Graphite is the only non-metallic mineral that can conduct electricity - a mineral that is resistant to heat and difficult to dissolve in water (Rizaty, 2022). It is the primary material for battery anodes and is commonly used in electronic devices such as cell phones, laptop computers, and electric vehicles (Indonesia Window, 2021). World graphite production in 2014 was around 1.17 million tonnes, with producing countries China (67%), India (15%), Brazil (7%), Canada (3%), Turkey (3%), and North Korea around 3% (Simandl, Paradis and Akam, 2015). The exploitation of graphite in Indonesia is still in the early stages of exploration, with a total resource of 31.3 million tonnes (Nursahan *et al.*, 2022). The global LIB anode market is estimated to reach US$ 9.2 billion in 2023 and will reach US$ 29.9 billion in 2033 with a compound annual growth rate (CAGR) of 12.5%. Such the CAGR is from 2023 to 2033 (Fact.MR, 2023). The anode material from the LIB recycling was successfully recovered by a mechanical separation using organic solvents, leaching processes, and heat treatment. So the sulfuric acid leaching process successfully separates the valuable elements and releases the lithium. The graphite in this anode material can be reused as a new LIB anode material.

Limited resources, high production costs, and widely open markets pose a challenge in producing battery-grade graphite to meet the growing demand for energy storage devices (Puviarasu *et al.*, 2023). One possible approach is to recycle the graphite anodes (AG) from the used LIB (Bhar *et al.*, 2022) into the new battery components (Ni'mah *et al.*, 2022) so that the use of LIB becomes more sustainable (Foster *et al.*, 2014). Challenge will specifically present a techno-economic study of recycling to get the graphite used in lithium-ion batteries of electric vehicles. Other valuable materials such as lithium, cobalt, and nickel are processed after separating the graphite anode.

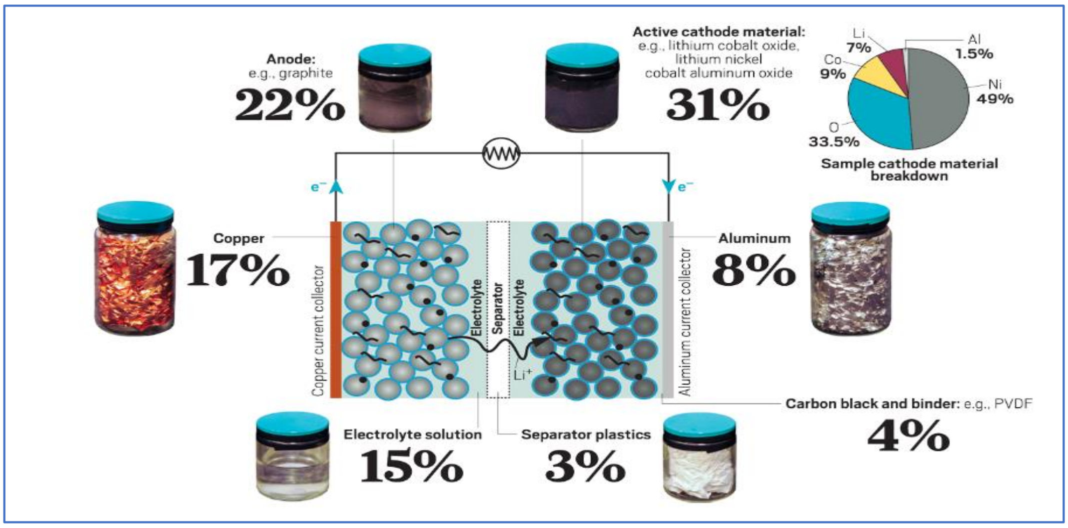

Figure 2. The material composition of a typical lithium-ion battery (Jacoby, 2019)

RESEARCH METHOD

Material

Raw materials needed in the leaching process of recycling graphite anodes are obtained through cooperation with partners/battery manufacturers throughout Indonesia. Meanwhile, the materials for the leaching process used dimethyl carbonate-DMC, N-methyl-2-pyrrolidone (NMP) H_2SO_4, and H_2O_2 solvents (Ni'mah *et al.*, 2022).

Equipment

Mechanical equipment used is assumed to be the same as that for the leaching process (Samarukha, 2020 in Triaswinanti *et al.*, 2023), namely containers for inserting the raw materials, tools for melting the batteries, tools for preparing the smelt before the dissolution material transportation, tools for dissolving material, a container to precipitate graphite from the leaching tank solution. Other equipment for this process includes presses for drying sediments pumps for moving liquids, tools for capturing hazardous materials and gaseous compounds from smelting, and heavy equipment for moving materials.

Data Collection and Analysis Methods

This study also, uses secondary data obtained from research reports, journals, and books published through the official website as a reference in calculations and analysis. Mechanical separation to remove plastic components is conducted by the organic solvents (using dimethyl carbonate-DMC), using dimethyl carbonate (DMC) and N-methyl-2-pyrrolidone (NMP) followed by a washing process with H_2SO_4 + H_2O_2 to purify graphite to be reused as anode material for the new LIB (Ni'mah *et al.*, 2022). This leaching process has low energy consumption, easy operation, and low emissions and costs. The steps involved in the leaching process are pre-treatment, leaching, separation, and recovery. Physical pre-treatment is carried out, is conducted by the crushing, sifting, current separation, separation of fractions including plastic, paper, ferrous and non-ferrous metals, powder/liquid electrodes, and separation of precious metals (Figure 3).

Techno-economics contains how to make a decision that is limited by various problems related to an engineer to produce the best choice from various alternatives. Decent decisions are based on analysis, techniques, and economic calculations (Zheng, Yu and Wang, 2019; Refaat *et al.*, 2023). Acquisition of literature is used as a guideline in calculations as assumptions in the analysis (Budiman, 2016). The economic analysis is intended to determine whether the graphite anode recycling industry from the used BEVs using the leaching process is profitable. Calculation of economic analysis with the following assumptions:

a) Physical development will be carried out in 2025 with a two-year construction and installation period, and the factory can operate in 2027;

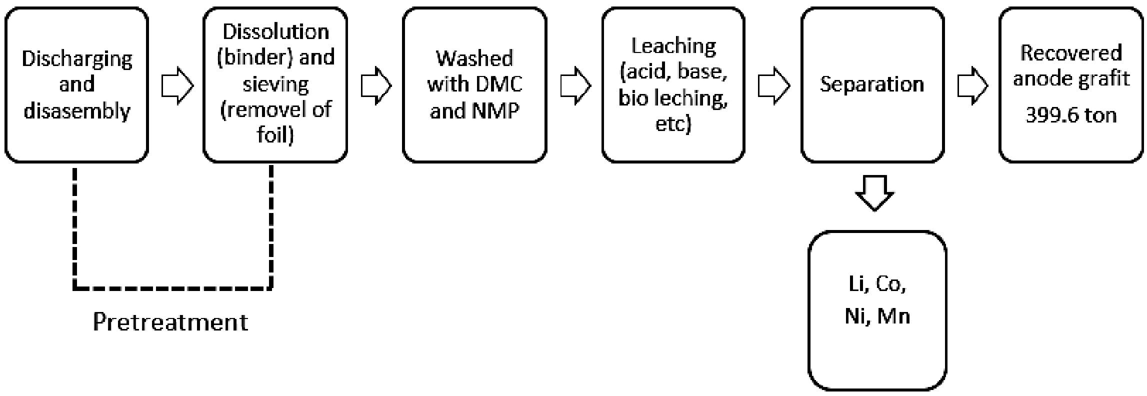

Figure 3. Flow chart of modified process recycling anode graphite (Sambamurthy, Raghuvanshi and Sangwan, 2021)

b) Capacity of 8,000 tons per year, 25% of the number of electric vehicles registered in Indonesia (Dai *et al.*, 2019; Alfarizi and Widyastuti, 2022) is roughly equivalent to the materials needed for 3.76 GWh of new cell battery (Mr. Sustainability, 2021);
c) The selling price of US$ 20,000 corresponds to the world market price of battery-grade graphite, $5,000 – USD 20,000 per tonne (Lai *et al.*, 2023);
d) Funds 70% and 30%;
e) The interest rate is 14.00% per year or 1.17% per month (Otoritas Jasa Keuangan, 2023);
f) February 2023 inflation rate = 5.47% (Bank Indonesia, 2023);
g) The company's existence is estimated at ten years, with depreciation of 10% per year.

The profitability level of these factories is evaluated based on the following:
1. Rate of Return on Investment;
2. Payment Time;
3. Break Even Point.

To review the above factors, an estimate is made of:
1. Estimated Total Equity Investment (TCI);
2. Estimated Total Cost of Production (TPC);
3. Project Compliance Profitability Analysis.

RESULTS AND DISCUSSION

Investment

An industry is feasible if it fulfills several requirements including guaranteed safety, and can bring profit. Investment is the funds or capital needed to build a company that is ready to operate, including start-up and working capital. An established factory is oriented not only to profit but also to return the investment which can be determined by conducting due diligence.

1. Estimated Capital Investment

Equipment prices change every year according to existing economic conditions. To estimate the price of equipment, an index is needed that can be used to convert past prices so that future prices can be obtained. The 2025 index price is found using the least square equation using index data from 2000 to 2016 (Figure 4).

Based on the graph, price index predictions are made with Y being the CEPCI (Chemical Engineering Plant Cost) index data and x being the year.

$$Y = 12.845x - 25288 \quad (1)$$

Determining the price of equipment in a specific year uses the following equation:

$$Ex = EyNxNy \quad (2)$$

Ex = tool price in 2025
Ey = equipment price in year y
Nx = index year 2022
Ny = index in 2016

Recycling graphite anodes from used electric vehicle lithium-ion batteries requires data regarding the consumption needs of materials/reagents and energy required, the cost, and reagent materials needed to recycle 1 kg of lithium battery cells using the leaching method. In this context, it is assumed that the reagent costs are standard worldwide and that the same amount of reagent is used for battery recycling through leaching process since this is an additional by-product or secondary product.

The cost of electricity consumption refers to the basic electricity tariff set by PLN in January 2023 for the industry at IDR 1,699.53/kWh (PLN, 2023). The full-scale recycling industry will have an initial capacity to process 8,000 tons per year, roughly the equivalent of the material needed for 3.7 GWh of new battery cells (Mr. Sustainability, 2021).

The cost of consuming dissolving water in the leaching tank and for other purposes, feeding capacity is 3000 kg/hour. It is assumed that the water consumption in recycling 1 kg of used batteries requires 5.69 liters of water (Samarukha, 2020). The water tariff is based on the Decree of the Bandung Regent in 2022, for business group III customers of IDR 14,300 per m3 or IDR 14,300 per liter (Tirta Raharja, 2022).

Assuming the use of diesel for logistics transportation within the factory environment, the cost of fuel consumption is 20 liters/hour (Samarukha, 2020). The price of biodiesel fuel as of April 1, 2023, is IDR 6,800.

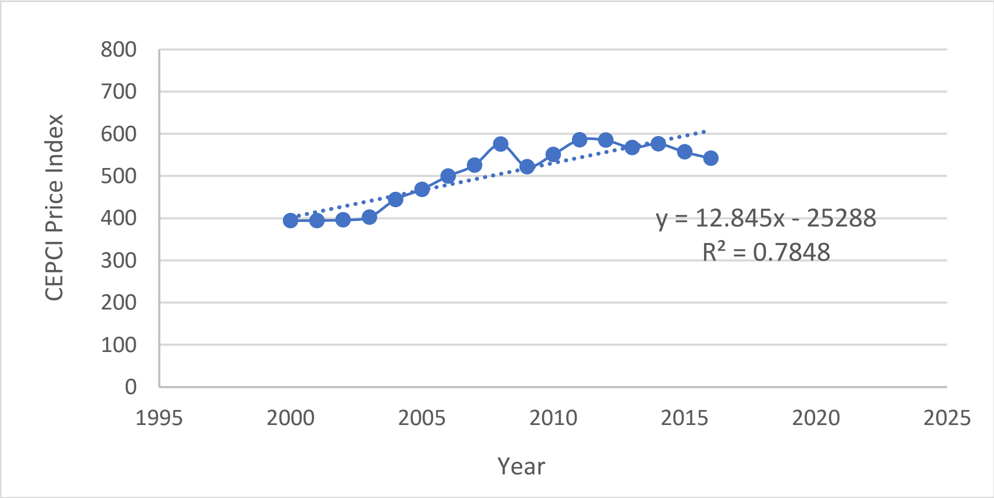

Figure 4. Price index

Table 1. Estimated price of graphite anode recycling equipment

No.	Equipment	Prices in 2014 (IDR)	Price Estimation in 2025 (IDR)
1	Hopper	558,557,100	719,138,400
2	Smelter	63,516,746,400	81,777,371,286
3	Granulator	285,773,400	367,931,274
4	Conveyor	1,480,825,800	1,906,552,966
5	Leaching Tank	1,313,403,000	1,690,997,270
6	Precipitation Tank	1,313,403	1,690,997
7	Filter Press	2,496,909,000	3,214,753,052
8	Slurry Pump	43,428,897	55,914,404
9	Wet Scrubber	1,082,475,000	1,393,679,069
10	Wheel Loader	1,082,475,000	1,393,679,069
	Total	71,861,907,000	95,929,742,476

Source: Peters, Timmerhaus and West (2004); Triaswinanti *et al.* (2023)

Table 2. Material cost for battery recycling process

No.	Chemical Material	Price (IDR)
1	Sulfuric Acid 98%, 35 Kg = IDR 1,234 (IndoTrading, July 14, 2023)	3,495,575,608
2	Sodium chloride, 1 kg = IDR 3,500 (IndoTrading, July 14, 2023)	3,565,598,400
3	Hydrogen peroxide Jerry Can 25Kg, IDR 900.00 (Sitara Perixide Limited, July 12, 2023)	2,858,617,600
4	Dimethyl carbonate, A13104, 99%, 100g = $23.2 (Chemical Book, July 14, 2023)	2,636,910,368
5	NMP N-Methyl-2-pyrrolidone Solvent CAS 872-50-4, 99.5%, 100g = $3.00 (Alibaba.Com, July 14, 2023)	2,713,285,486
	Total	15,269,987,462

Source: Samarukha (2020); Triaswinanti *et al.* (2023)

Labor in recycling graphite anodes from used lithium-ion electric vehicle batteries is needed in all stages; from pre-treatment, leaching, separation, and recovery, to making new battery components. The following is a calculation of the labor costs required to recycle graphite anodes from used lithium-ion electric vehicle batteries. The required workforce is assumed to be 217 people, with details of 100 people for production, 32 people for engineering, 23 people for supervision, 10 people for research, 12 people for distribution and marketing, and 40 people for general purposes.

Table 3. Estimation energy cost for battery recycling leaching processes

No.	Energy Type	Total cost Energy per Year (IDR)
1	Electricity	9,274,636,800
2	Water	758,181,120
3	Fuel	806,860,800
4	Labor	7,200,000,000
	Total	15,269,987,462

Source: Samarukha (2020) in Triaswinanti *et al.* (2023)

2. Fixed Capital Investment (FCI)

Fixed Capital Investment is the cost required to build industrial facilities physically. FCI consists of direct costs and indirect costs. Fixed capital investment in the design of the AG recycling plant from used LIB is shown in Table 4.

3. Working Capital Investment (WCI)

Working Capital Investment consists of the total amount of money invested for stocks of raw materials and supplies, stock of final products and semi-finished products in the process of being made, money received (account receivable), cash for monthly payment of operating costs such as salaries, wages, and raw materials, paid money (account payable), and taxes paid (taxes payable). The WCI for leaching recycling of graphite anodes from used electric vehicle lithium-ion batteries is IDR 53,206,592,435.

4. Total Production Cost (TPC)

Represents the total production cost of methyl acrylate consisting of:

1) Manufacturing Cost
   Capital used for production costs is divided into three types: direct production costs, fixed costs, and indirect costs. Direct production costs are used to directly finance a process such as raw materials, labor, supervisors, maintenance, etc. Fixed costs are costs that are incurred both when the factory is in production or not. These costs include depreciation, taxes, and insurance. Indirect costs are incurred to fund things that indirectly help the production process.

Table 4. Estimation of fixed-capital investment by the percentage of delivered equipment

No.	Components	Cost (IDR)
1	Direct Cost	
	Purchased equipment cost	95,929,742,476
	Purchased equipment installation, 39% E	37,412,599,566
	Instrumentation (installed), 28% E	26,860,327,893
	Piping (installed), 31% E	29,738,220,168
	Electricity (Installed), 10%	9,592,974,248
	Buildings (including services), 22% E	21,104,543,345
	Yard improvements, 10% E	9,592,974,248
	Service facilities (installed), 55% E	52,761,358,362
	Land, 6% E	5,755,784,549
Total direct plant cost D		288,748,524,853
2	Indirect Cost	
	Engineering and supervision, 32% E	14,776,804,562
	construction expenses, 34% E	14,776,804,562
Total direct and indirect cost (D + I)		29,553,609,124
	Contractor's fee, 5% (D + I)	1,477,680,456
	Contingency, 10% (D + I)	2,955,360,912
Fixed Capital Investment (FCI)		318,302,133,977
Working Capital Investment, 15 % TCI		53,206,592,435
Total Cost Invesment (TCI)		371,508,726,412

Source: Peters and Timmerhaus (1991)

Table 5. Manufacturing cost component

No	Components	Cost (IDR)
1	Labor	14,424,000,000
2	Supervision	4,146,000,000
3	Maintenance	31,830,213,398
4	Plant supplies	15,269,987,462
5	Royalty and patens	3,602,419,920
6	Utility	1,477,680,456
Direct Manufacturing Cost (DMC)		52,180,301,236
7	Payroll overhead	2,785,500,000
8	Laboratory	1,857,000,000
9	Plant overhead	9,285,000,000
10	Packaging	14,409,679,680
Indirect Manufacturing Cost (IMC)		28,337,179,680
11	Depreciation	31,830,213,398
12	Property taxes	3,183,021,340
13	Insurance	3,183,021,340
Fixed Manufacturing Cost (FMC)		35,013,234,738
Manufacturing Cost (MC)		115,530,715,653
14	Administration	4,146,000,000
15	Distribution & marketing	23,106,143,131
16	R&D cost	9,242,457,252
17	Financing	18,575,436,321
General Expenses (GE)		55,070,036,703
Total Production Cost (TPC)		170,600,752,357

1 USD = 15,161.7 IDR
TPC = MC + GE
Source: Aries and Newton (1955)

2) General Expenses
Apart from production costs, general costs include administration, sales expenses, research, and finance. The general expenses of the factory are shown in the following Table 6.

Table 6. General expenses

General Expenses		
1	Administration	4,146,000,000
2	Distribution and Selling	23,106,143,131
3	Research and Development	9,242,457,252
4	Financing	18,575,436,321
	Total General Expenses	55,070,036,703

Sales, Profitability, and Project Feasibility Profitability Analysis

1. Sales and Profits

Sales are products that can be sold, and product selling prices can be based on market prices. It can also be based on the minimum price calculated by the factory so that the difference to the market price is an additional profit by the factory-estimated gross profit and net profit (Table 7).

Profit is the result obtained from the difference between sales and the total cost of production. Profit can be defined as excess revenue after deducting expenses. Net profit amount earned IDR 132,748,867,750 annually.

2. Project Feasibility and Profitability Analysis

Net Present Value (NPV)
NPV is the difference between the net present value (total net cash flows) over the project's life and the investment's present value (Zainuri, 2021). The difference between the range of current future income assessed (using a discount factor) and capital expenditures made today is called the net present value (Hakizimana and Kim, 2016). The calculation of NPV used in this study is in equation (3) (Zainuri, 2021).

$$NPV(i)= \sum_{t=1}^{n} B_t \ (1+i)^{-t} - \sum_{t=0}^{n} C_t \ (1+i)^{-t} \quad .... (3)$$

Table 7. Estimated profits

Sales		IDR 360,241,992,000
Manufacturing Cost	IDR 115,530,715,653	
General expense	IDR 55,070,036,703	
Total Production Cost		IDR 170,600,752,357
Profit before taxes		IDR 189,641,239,643
Income taxes (30%)		IDR 56,892,371,893
Profit after taxes		IDR 132,748,867,750

1 USD = 15,161.7 IDR, based on the conversion rate of July 12, 2023
Source: Aries and Newton (1955); Ifa and Nurdjannah (2019)

In this case:

NPV(i) = present net value (profit) at interest rate-i per unit of time.
Bt = total revenue (benefit) or benefits for business activities at time t.
Ct = total costs incurred (cost) for business activities at time t.
(1+i)-1 = present value factor or discount factor, a correction factor for the effect of time on the value of money in period t with an interest rate-i at time t.
i = Interest rate used
t = t-th time period

The criterion for a business to meet the economic feasibility is if the NPV (i) is greater than zero, which is synonymous with a project profit rate greater than zero. A discount rate of 12% to 20% is the interest rate considered logical in business judgments to refuse or accept (Calhoun and Harkins, 2021).

The calculation results show, with an investment age of 10 years, the NPV is positive, namely IDR 388,675,699,788, - meaning that this project is feasible to run.

Internal Rate of Return (IRR)

IRR is the rate of return on an investment when the Net Present Value is zero. An investment is said to be feasible and profitable if the IRR value is greater than the assumed cost of capital. To provide a better understanding of the IRR, another understanding that can be used as a guideline is that the IRR is an interest rate that will make the total present value of future proceeds expected to be received (PV of future proceeds) equal to the total present value of capital expenditure (PV of capital). Outlays). The IRR value is calculated by equation (4) (Zainuri, 2021).

$$IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2}(i_1 - i_2) \quad \text{.........................} \quad (4)$$

In this case:

i_1 = Interest rate that produces a positive NPV;
i_2 = Interest rate that produces a negative NPV;
NPV_1 = positive NPV;
NPV_2 = negative NPV.

The feasibility level seen from the IRR is compared with the existing interest rate. Business ventures can be feasible if the IRR exceeds the existing interest. In this case, the IRR of around 33.79% per year is huge compared to the deposit interest rate of 14.00% per year.

Payback Period (PP)

PP determines the time or period investors get back their investment costs. The PP is determined by calculating the time required for the accumulated cash flows to change from a negative value to a positive value, where the profit value of the investment is equal to the investment cost. In other words, the PP is the minimum time to return the initial investment in cash flow based on total revenue minus all costs except depreciation costs. Mathematically, PP calculations can be formulated as follows:

$$\text{Payback Period (PP)} = \frac{\text{Investment Value}}{\text{Net Cash Inflow}} \times \text{period of time} \quad \text{....................} \quad (5)$$

Table 8. Net present value

Tahun	Net Cash Flow	Present Value		
		12.00%	33%	34%
0	371,508,726,412	371,508,726,412	371,508,726,412	371,508,726,412
1	132,748,867,750	118,525,774,777	99,811,178,760	99,066,319,217
2	132,748,867,750	105,826,584,622	75,045,999,067	73,930,088,968
3	132,748,867,750	94,488,021,984	56,425,563,209	55,171,708,185
4	132,748,867,750	94,488,021,984	42,425,235,495	41,172,916,556
5	132,748,867,750	75,325,272,628	31,898,673,305	30,726,057,131
6	132,748,867,750	67,254,707,703	23,983,964,891	22,929,893,382
7	132,748,867,750	60,048,846,164	18,033,056,309	17,111,860,732
8	132,748,867,750	53,615,041,218	13,558,688,954	12,770,045,323
9	132,748,867,750	47,870,572,516	10,194,502,973	9,529,884,569
10	132,748,867,750	42,741,582,603	7,665,039,829	7,111,854,156
	NPV	388,675,699,788	7,533,176,379	(1,988,098,194)

Table 9. Payback period

Year	Net Cash Flow	Payback Period (Initial capital - net cash flow)
0	(371,508,726,412.16)	(371,508,726,412.16)
1	132,748,867,750.40	(238,759,858,661.76)
2	132,748,867,750.40	(106,010,990,911.36)
3	132,748,867,750.40	26,737,876,839.04
4	132,748,867,750.40	159,486,744,589.45
5	132,748,867,750.40	292,235,612,339.85
6	132,748,867,750.40	424,984,480,090.25
7	132,748,867,750.40	557,733,347,840.65
8	132,748,867,750.40	690,482,215,591.05
9	132,748,867,750.40	823,231,083,341.45
10	132,748,867,750.40	955,979,951,091.86

Based on such calculations, the PP in two years and ten months is considered a quick profit for a return on capital.

Sensitivity and Risk Analysis

Sensitivity analysis examines how parameter changes in the financial-economic aspect can affect selected decisions. Here it will be seen whether or not the decisions taken are sensitive to changes in specific parameters. If certain parameters change with relatively large variations but do not result in a decision, then the decision is said to be insensitive to the element in question. Conversely, if there is only a small change in a parameter, and it turns out to result in a change in the decision taken, then the decision is said to be sensitive to the parameter. In the sensitivity analysis, it is predicted that there will be an increase in production costs and a decrease in the selling price of graphite anode from 5% to 20% (Figures 5 and 6).

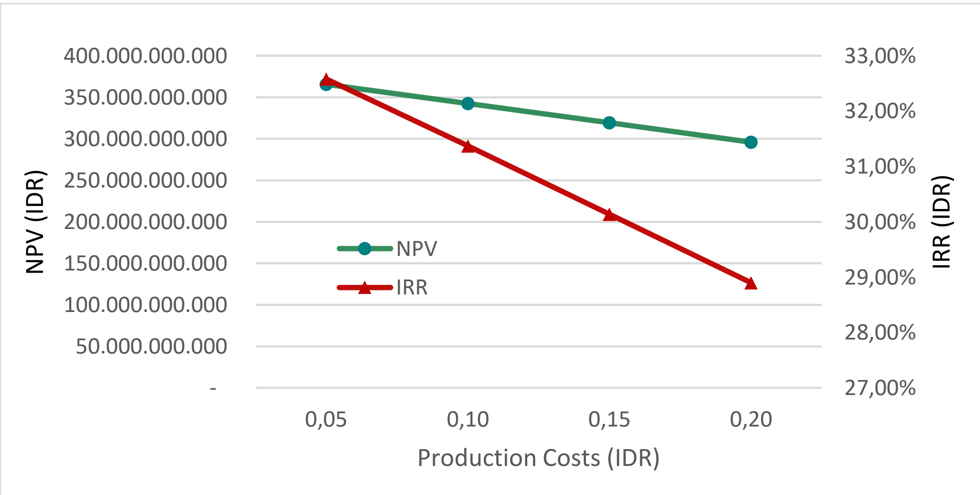

Figure 5. Sensitivityof an increase in production costs

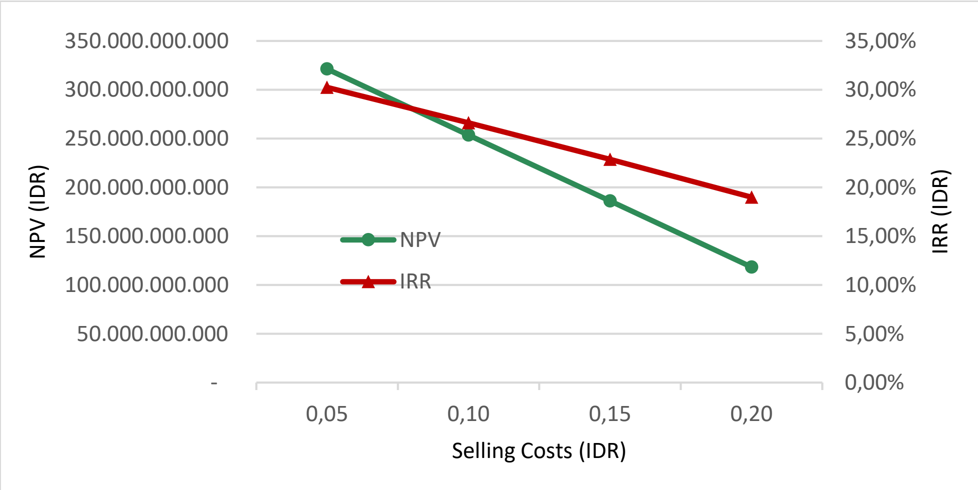

Figure 6. Sensitivity of a decline in selling prices

From the sensitivity analysis, it can be concluded that this project is still profitable if there is an increase in production costs up to 20% and a decrease in the selling price of graphite up to 20% or USD 12,000 per ton. Through this sensitivity analysis, investors/ companies can make decisions and prepare strategic steps to anticipate this situation.

CONCLUSIONS AND SUGGESTION

Conclusions

This leaching process uses this approach to recycle graphite anodes from the used LIB into new battery components, and it has low energy consumption, easy operation, and low emissions and costs. In addition to the possible negative impact on the environment from the disposal of used LIBs, recycling is a top priority in many parts of the world. From an economic point of view, the industry has a significant profit potential to produce new LIBs. With an excellent selling price, this is a beautiful business opportunity in connection with LIB recycling which so far has been more inclined towards LIB recycling for precious metals only.

Suggestion

LIB's graphite anode recycling industry needs attention. Indonesia's electric vehicle population continues to grow, and much LIB waste will be generated. Economic analysis with simulations and assumptions is expected to be close to actual conditions. However, better data quality is needed to increase accuracy in calculations. More in-depth observations need to be made.

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REFERENCES

Alfarizi, M.K. and Widyastuti, A.Y. (2022) *Kemenhub ungkap jumlah kendaraan listrik RI baru 31.827 unit dari target 100 Ribu*, *Tempo.co*. Available at: https://bisnis.tempo.co/read/1651913/kemenhub-ungkap-jumlah-kendaraan-listrik-ri-baru-31-827-unit-dari-target-100-ribu (Accessed: 3 June 2023).

Aries, R.S. and Newton, R.D. (1955) *Chemical engineering cost estimation*. New York: Mc. Graw Hill Book Company.

Autthawong, T., Yodbunork, C., Yodying, W., Boonprachai, R., Namsar, O., Yu, A., Chimupala, Y. and Sarakonsri, T. (2022) ‘Fast-charging anode materials and novel nanocomposite design of rice husk-derived SiO2 and Sn nanoparticles self-assembled on TiO2 (B) nanorods for lithium-ion storage applications’, *ACS Omega*, 7(1), pp. 1357–1367. Available at:

https://doi.org/10.1021/acsomega.1c05982.

Bank Indonesia (2023) *Data inflasi*, *bi.go.id*. Available at: https://www.bi.go.id/id/statistik/indikator/data-inflasi.aspx (Accessed: 9 June 2023).

Bhar, M., Dey, A., Ghosh, S., van Spronsen, M.A., Selvaraj, V., Kaliprasad, Y., Krishnamurthy, S. and Martha, S.K. (2022) 'Plasma jet printing induced high-capacity graphite anodes for sustainable recycling of lithium-ion batteries', *Carbon*, 198, pp. 401–410. Available at: https://doi.org/10.1016/j.carbon.2022.07.027.

Budiman, A. (2016) 'Kajian tekno ekonomi potensi sampah kota Pontianak sebagai sumber pembangkit listrik tenaga uap (PLTU)', *ELKHA*, 8(1), pp. 1–5. Available at: https://doi.org/10.26418/elkha.v8i1.14385.

Calhoun, K. and Harkins, D.W.R. (2021) *Understand the discount rate used in a business valuation*, *Mercer Capital*. Available at: https://mercercapital.com/article/understand-the-discount-rate-used-in-a-business-valuation/ (Accessed: 23 May 2023).

Dai, Q., Spangenberger, J., Ahmed, S., Gaines, L., Kelly, J.C. and Wang, M. (2019) *EverBatt: A closed-loop battery recycling cost and environmental impacts model*. Argonne National Laboratory.

Fact.MR (2023) *LIB anode market outlook (2023 to 2033)*, *Fact.MR*. Available at: https://www.factmr.com/report/4068/lib-anode-market (Accessed: 14 June 2023).

Foster, M., Isely, P., Standridge, C.R. and Hasan, M.M. (2014) 'Feasibility assessment of remanufacturing, repurposing, and recycling of end of vehicle application lithium-ion batteries', *Journal of Industrial Engineering and Management*, 7(3), pp. 698–715. Available at: https://doi.org/10.3926/jiem.939.

Fransson, L., Eriksson, T., Edström, K., Gustafsson, T. and Thomas, J.. (2001) 'Influence of carbon black and binder on Li-ion batteries', *Journal of Power Sources*, 101(1), pp. 1–9. Available at: https://doi.org/10.1016/S0378-7753(01)00481-5.

Hakizimana, J. de D.K. and Kim, H.-T. (2016) 'Peat briquette as an alternative to cooking fuel: A techno-economic viability assessment in Rwanda', *Energy*, 102, pp. 453–464. Available at: https://doi.org/10.1016/j.energy.2016.02.073.

Ifa, L. and Nurdjannah (2019) *Ekonomi Pabrik.* Makassar: Wade Group.

Indonesia Window (2021) *Permintaan grafit alam diperkirakan naik 154 persen setiap tahun*, *indonesiawindow.com*. Available at: https://indonesiawindow.com/permintaan-grafit-alam-diperkirakan-naik-154-persen-setiap-tahun/ (Accessed: 12 June 2023).

Jacoby, M. (2019) 'It's time to get serious about recycling lithium-ion batteries', *Chemical & Engineering News*, 97(28), pp. 29–32.

Kang, Y., Deng, C., Chen, Y., Liu, X., Liang, Z., Li, T., Hu, Q. and Zhao, Y. (2020) 'Binder-free electrodes and their application for Li-Ion batteries', *Nanoscale Research Letters*, 15(1), p. 112. Available at: https://doi.org/10.1186/s11671-020-03325-w.

Lai, Y., Zhu, Xianqing, Li, J., Gou, Q., Li, M., Xia, A., Huang, Y., Zhu, Xun and Liao, Q. (2023) 'Recovery and regeneration of anode graphite from spent lithium-ion batteries through deep eutectic solvent treatment: Structural characteristics, electrochemical performance and regeneration mechanism', *Chemical Engineering Journal*, 457, p. 141196. Available at: https://doi.org/10.1016/j.cej.2022.141196.

Liu, K., Yang, S., Luo, L., Pan, Q., Zhang, P., Huang, Y., Zheng, F., Wang, H. and Li, Q. (2020) 'From spent graphite to recycle graphite anode for high-performance lithium ion batteries and sodium ion batteries', *Electrochimica Acta*, 356, p. 136856. Available at: https://doi.org/10.1016/j.electacta.2020.136856.

Moore, S.A., Arefin, M.R. and Rosenfeld, H. (2018) 'Generating anxiety, short-circuiting desire: Battery waste and the capitalist phantasy', *Environment and Planning D: Society and Space*, 36(6), pp. 1081–1100. Available at: https://doi.org/10.1177/0263775818777249.

Mossali, E., Picone, N., Gentilini, L., Rodrìguez, O., Pérez, J.M. and Colledani, M. (2020) 'Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments', *Journal of Environmental Management*, 264, p. 110500. Available at: https://doi.org/10.1016/j.jenvman.2020.110500.

Mr. Sustainability (2021) *Battery recycling, made by Northvolt: Creating a circular European battery industry*, *mr-sustainability.com*. Available at: https://www.mr-sustainability.com/stories/2021/battery-recycling-northvolt (Accessed: 4 July 2023).

Nguyen-Tien, V., Dai, Q., Harper, G.D.J., Anderson, P.A. and Elliott, R.J.R. (2022) 'Optimising the geospatial configuration of a future lithium ion battery recycling industry in the transition to electric vehicles and a circular economy', *Applied Energy*, 321, p. 119230. Available at: https://doi.org/10.1016/j.apenergy.2022.119230.

Ni'mah, atim L., Hidayatullah, N.A.A.K., Suprapto, S., Subhan, A. and Hardiansyah, A. (2022) 'Recovery of graphite from lithium ion batteries leaching using sulfuric acid as anode materials', *Moroccan Journal of Chemistry*, 10(3), pp. 396–404. Available at: https://doi.org/https://doi.org/10.48317/IMIST.PRSM/morjchem-v10i3.32667.

Nursahan, I., Heditama, D.M., Sunuhadi, D.N., Mulyadi, A.D., Eddy, H.R., Juarsa, A., Wibisono, S.A., Ibrahim, M.A., Oktaviani, P., Hidayat, R., Fatimah, Hermawan, D., Mustofa, S.A., Permana, L.A. and Rustina, T.S. (2022) *Neraca sumber daya dan cadangan mineral, batubara, dan panas bumi Indonesia Tahun 2021*. Edited by M. Awaludin, S.S.R. Susilawati, and A. Munandar. Bandung: Pusat Sumber Daya Mineral, Batubara dan Panas Bumi.

Otoritas Jasa Keuangan (2023) *Suku bunga dasar kredit*, *ojk.go.id*. Available at: https://ojk.go.id/id/kanal/perbankan/pages/suku-bunga-dasar.aspx (Accessed: 11 May 2023).

Peters, M.S. and Timmerhaus, K.D. (1991) *Plant design and economics for chemical engineers*. 4th edn. New York: Mc. Graw Hill Book Company.

Peters, M.S., Timmerhaus, K.D. and West, R.E. (2004) *Plant design and economics for chemical engineers*. 5th edn. New York: Mc. Graw Hill Book Company.

Puviarasu, M., Asokan, P., Sherif, S.U., Mathiyazhagan, K. and Sasikumar, P. (2023) 'A STEEP based hybrid multi-criteria decision making model for the evaluation of battery recycling plant location', *Journal of Advances in Management Research*, 20(2), pp. 234–264. Available at: https://doi.org/10.1108/JAMR-06-2022-0124.

Qian, G., Li, Z., Wang, Y., Xie, X., He, Y., Li, J., Zhu, Y., Xie, S., Cheng, Z., Che, H., Shen, Y., Chen, L., Huang, X., Pianetta, P., Ma, Z.-F., Liu, Y. and Li, L. (2022) 'Value-creating upcycling of retired electric vehicle battery cathodes', *Cell Reports Physical Science*, 3(2), p. 100741. Available at: https://doi.org/10.1016/j.xcrp.2022.100741.

Rallo, H., Canals Casals, L., De La Torre, D., Reinhardt, R., Marchante, C. and Amante, B. (2020) 'Lithium-ion battery 2nd life used as a stationary energy storage system: Ageing and economic analysis in two real cases', *Journal of Cleaner Production*, 272, p. 122584. Available at: https://doi.org/10.1016/j.jclepro.2020.122584.

Refaat, M.M., Aleem, S.H.E.A., Atia, Y., Zahab, E.E.D.A. and Sayed, M.M. (2023) 'A new decision-making strategy for techno-economic assessment of generation and transmission expansion planning for modern power systems', *Systems*, 11(1), p. 23. Available at: https://doi.org/10.3390/systems11010023.

Rizaty, M.A. (2022) *Deretan negara produsen grafit terbesar di dunia*, *Katadata Media Network*. Available at: https://databoks.katadata.co.id/datapublish/2022/05/27/deretan-negara-produsen-grafit-terbesar-di-dunia (Accessed: 31 July 2023).

Samarukha, I. (2020) *Recycling strategies for end-of-life Li-ion batteries from heavy electric vehicles*. KTH Industrial Engineering and Management.

Sambamurthy, S., Raghuvanshi, S. and Sangwan, K.S. (2021) 'Environmental impact of recycling spent lithium-ion batteries', *Procedia CIRP*, 98, pp. 631–636. Available at: https://doi.org/10.1016/j.procir.2021.01.166.

Shahjalal, M., Roy, P.K., Shams, T., Fly, A., Chowdhury, J.I., Ahmed, M.R. and Liu, K. (2022) 'A review on second-life of Li-ion batteries: Prospects, challenges, and issues', *Energy*, 241, p. 122881. Available at: https://doi.org/10.1016/j.energy.2021.122881.

Simandl, G.J., Paradis, S. and Akam, C. (2015) 'Graphite deposit types, their origin, and economic signifi cance', in *Symposium on Critical and Strategic Materials*. British Columbia Geological Survey, pp. 163–171.

Statista (2023) *Electric vehicles - Worldwide*, *statista.com*. Available at: https://www.statista.com/outlook/mmo/electric-vehicles/worldwide (Accessed: 9 July 2023).

Tirta Raharja (2022) *Tarif air minum tahun 2022*, *tirtaraharja.co.id*. Available at: https://tirtaraharja.co.id/berita/detail/tarif-air-minum-tahun-2022# (Accessed: 9 June 2023).

Triaswinanti, R., Triastomo, R., Puspita, A.N.G. and Hapid, A. (2023) 'Studi tekno-ekonomi proses pirometalurgi daur ulang baterai lithium manganese oxide (LMO) dan lithium iron phosphate (LFP)', *J@ti Undip: Jurnal Teknik Industri*, 18(2), pp. 94–108. Available at: https://doi.org/10.14710/jati.18.2.94-108.

Winslow, K.M., Laux, S.J. and Townsend, T.G. (2018) 'A review on the growing concern and potential management strategies of waste lithium-ion batteries', *Resources, Conservation and Recycling*, 129, pp. 263–277. Available at: https://doi.org/10.1016/j.resconrec.2017.11.001.

Zainuri (2021) *Ekonomi teknik*. 1st edn. Edited by E. Martinelly. Padang: CV. Jasa Surya.

Zhang, W., Xu, C., He, W., Li, G. and Huang, J. (2018) 'A review on management of spent lithium ion batteries and strategy for resource recycling of all components from them', *Waste Management & Research: The Journal for a Sustainable Circular Economy*, 36(2), pp. 99–112. Available at: https://doi.org/10.1177/0734242X17744655.

Zhao, Y., Pohl, O., Bhatt, A.I., Collis, G.E., Mahon, P.J., Rüther, T. and Hollenkamp, A.F. (2021) 'A review on battery market trends, second-life reuse, and recycling', *Sustainable Chemistry*, 2(1), pp. 167–205. Available at: https://doi.org/10.3390/suschem2010011.

Zheng, D., Yu, L. and Wang, L. (2019) 'A techno-economic-risk decision-making methodology for large-scale building energy efficiency retrofit using Monte Carlo simulation', *Energy*, 189, p. 116169. Available at: https://doi.org/10.1016/j.energy.2019.116169.