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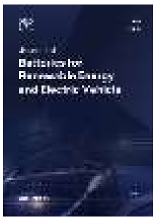

Analysis Study on Scaling Up Production of Lithium-Ion Batteries (LIB) Cathode Material at National Battery Research Institute

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A B S T R A C T

Innovation for energy storage becomes essential for advancing the electrification goal. Over the past ten years, the trend toward electric vehicles and renewable energy has placed an unexpectedly high demand on battery technology. The development of lithium-ion batteries (LIB) has been touted as a revolution in energy storage technology. Due to its promising performance, LIB has not only performed well for electronic applications but is also well-known for its scalability for mass production. Although it is projected that LIB will continue to dominate the market for the succeeding ten years, the rise of battery giga-factories is still sluggish. The biggest barrier to increase end-to-end battery production on an industrial scale is the complexity of the manufacturing process and the number of machines used. Because the viability of the firm may be impacted by inaccurate calculations regarding the battery production chain. Investigating how to increase battery cathode production from a laboratory to an industrial scale is therefore important. National Battery Research Institute, one of Indonesia's top battery research centers, contributed as the study's subject. The calculation was focused on NMC 811 cathode active material by considering cost structure factor such as raw materials, machinery, power consumption, and manpower. The result has successfully estimated the total cost for scaling-up 100 kg production of NMC 811 cathode per batch or 36 Tons in a year. As a note, the data that was discussed in this manuscript limited on machinery, power consumption, and manpower aspect. While raw material cost will be discussed in detail, separately in another article.

INTRODUCTION

The electrification trends around the world are widely embraced. The market trend for the clean transition has been dominated for the past five years by the automobile sector's move toward e-mobility and the energy sector's massive shift toward renewable energy sources. The robustness of energy storage systems is crucial to both industries[1].

For the past several decades, lithium-ion batteries (LIB) have been acknowledged as the cutting-edge in energy storage technology. This kind of battery has been extensively employed in a variety of electronic-based applications, including electric vehicles. Its superiority over other energy storage technologies was attributed to its high energy density, high power density, and long life cycle[2]–[4].

Another LIB competitive advantage lays on its affordable cost. The biggest portion of LIB production comes from its material such as cathode, anode, and separator. In fact, LIB cell manufacturing costs are extremely susceptible to scrap and process deviation since material costs account for roughly 75% of the overall manufacturing cost. Fortunately, since Whittingham

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discovered intercalation electrodes in the 1970s, Goodenough *et al.* created some essential cathode materials (spinel, layered, and polyanion) in the 1980s and 1990s, and Yoshino developed the first secure, producible LIB using $LiCoO_2$ as the cathode and carbon/graphite as the anode, the production cost has been plummeted over time. Such significant progress has affected energy and power density, cycle life as well as safety[5].

Globally, the price of LIBs has decreased from about USD 1,000/kWh in the early 2000s to about USD 200/kWh at the moment. At the same time, in just a decade, the specific energy density has increased from 150 Wh/kg to over 300 Wh/kg[2], [4]. In Europe specifically, the price has decreased to EUR 75/kWh in 2022 from EUR 400/kWh in 2013. Although certain advanced battery technologies beyond LIBs, like solid-state batteries, sodium-ion batteries, lithium-sulfur batteries, lithium-air batteries, and others, have been developed and suggested. According to predictions, LIB will likely continue to rule the market for at least the ensuing ten years[6].

Obviously, the battery production process is divided into two stages, from raw material to cathode and cathode to the battery cell. The process of turning raw materials (nickel sulfate, manganese sulfate, and cobalt sulfate) into the active component of the NMC cathode begins with a chemical reaction. NMC cathode active material is then used in the cell fabrication process[7]–[9]. However, only a few companies in Indonesia are able to make batteries end-to-end due to the complexity of the battery production process and the number of machines utilized [10], [11]. Because a thorough estimate of the complete manufacturing chain is necessary to prevent business failure[10].

Therefore, it is essential to investigate the calculation on scale up battery production for shifting from the laboratory invention into producible industry. This research has pointed two main objectives, battery production analysis and scale-up calculation, particularly on the first stage of the production process from raw material into cathode active material at National Battery Research Institute. It is expected, this study can provide the insight for industry to maintain their efficiency on LIB production.

METHODOLOGY

Three different approaches—literature review, interview, and observation—have been employed to achieve the study's goals. To learn new information and comprehend the battery production process, the primary way is literature research. The issues can then be adequately identified and analyzed. Researching, reading, analyzing, assessing, and summarizing a variety of scientific articles are all steps in the literature study process. These approaches can address research concerns and extend the perspective on potential solutions by integrating perspectives and ideas from a variety of empirical data.

A company expert was interviewed after various secondary data were gathered through literature studies. This step's goal is to determine the production objective. Some information has been released publicly, including the goal of the production process, the specifications of the machinery, and the actual state of the production line, as well as any challenges. The actual production process, including input and output in each line of production, was also observed while conducting the interview. Fig. 1 clearly shows the research methodology that has been adopted for this study.

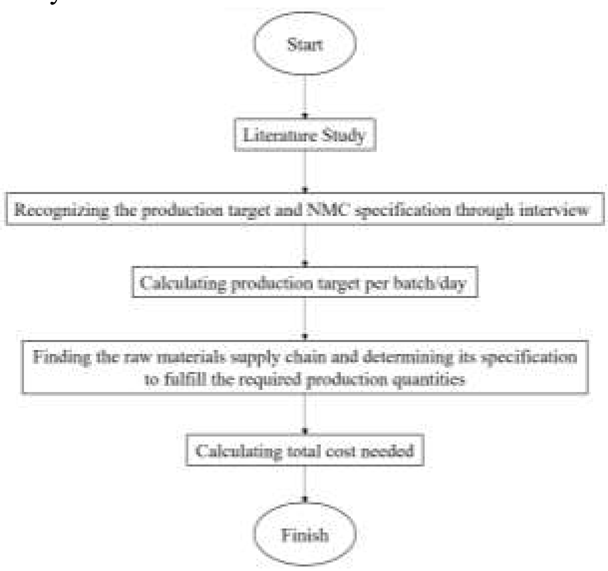

Fig. 1 Research Methodology

The aim to be achieved through this research is study the scaling-up for the first stage of battery production process from raw material to cathode active materials. Furthermore, the research at this company provides some prominent suggestions for solving the company problem. Limitations for this research are the scope of the problem or an attempt to limit the scope of the problem that is too broad. So that the work can be carried out carefully. Based on the research aim, limitations for this research are as follows: (1) This research will only study the first stage of battery production process, from raw materials to cathode active materials, (2) this research will study the escalation of cathode production capacity with the exact target 100 kg per batch, (3) the specification of the cathode under study is NMC 811 with hydroxide as the precipitant.

Besides some limitations, there are also a few assumptions that the research remains focused. Assumptions need to be determined before conducting the research. This assumption is used as the basic thesis in conducting research. The assumption that is applied in this work are as follows: (1) there are no failures in the product, (2) All supporting tools and machines are ready for use, and (3) the procedures have no significant changes throughout the research process.

RESULTS AND DISCUSSION

LIB Production

The fabrication of cathodes and anodes is the first step in the production of LIB. Cathodes are made from basic materials through a number of steps. The methods include precursor synthesis, washing, drying, mixing, sifting, and calcining. NMC cathode active material, which is used in the following stage of battery construction, is the process' final output. Active materials (NMC) are combined with a binder and carbon black to create a cathode paste, which is then used to create cathodes. Aluminum foil, which functions as a current collector, is coated with cathode paste [1], [9].

In contrast, anodes are created by coating a copper foil current collector with a paste made of a binder and graphite. After that, the foils are dried and pressed to the required thickness and density[11]. The foils are then cut to the required size and placed into the battery cell container as the following stage in the process. Afterward, electrolyte is poured and the cells are sealed. The steps for generating cathode active material will be described in full below [2], [12], [13], [14].

Co-Precipitation

Co-precipitation has emerged as a popular technique for producing cathode active material. Co-precipitation is a straightforward, affordable, and commercially feasible method that can be utilized to synthesize critical oxide materials for technology. Co-precipitation is the process by which chemicals that are typically soluble under the conditions used are carried down by a precipitate. The co-precipitation approach is a bottom-up synthesis technique used to produce microscopic particles with a diameter of a few nanometers [7], [8].

The cathode production process starts with this step. Incorporating MSO_4 such as nickel sulfate, manganese sulfate, and cobalt sulfate as well as precipitants such natrium hydroxide and ammonia is the aim of this procedure. For this procedure, the MSO_4 and precipitant are thoroughly mixed in a continuous stir tank reactor over the duration of about 24 hours.

Precursor Filtering & Washing

After the Co-precipitation process, the mixture of the MSO_4 and the precipitant is shaped like a slurry or condensed water. The purpose of this process is to wash away the dissolved sulphates and carbonates from the precipitates that were used in the Co-precipitation process before and to remove any excess water (demineralize water) that was also used in the Co-precipitation process before[9]. This precursor filtering & washing process uses a filter press machine to filter and wash the slurry.

Precursor Drying

The next step of the production process after the filtering and washing process is the drying process. The purpose of this process is to drain any excess water that is still contained in the precursor. This process will use an oven as a heater or dryer. The drying temperature is around 80-120 °C for 12 hours. After the drying process, the precursor will be transformed into dry powder.

Precursor + Lithium

After all the precursor dried in the drying process before, the next step of production is adding lithium powder to the precursor. Lithium needs to be mixed with the precursor to make a cathode. To mix the precursor and lithium together, a ball mill machine is used. The goal of this process is only to mix the lithium and precursor.

Calcination

Calcination is the heating of solids to a high temperature for the purpose of removing volatile substances, oxidizing a portion of mass, or rendering them friable. Calcination itself is a 2-stage process. For the first process about 450-480 °C for 3 to 5 hours under flowing oxygen enriched air, and for the second process followed by 750 °C for 12 to 15 hours [7], [8].

Cathode Sieving

Sieving is a physical mechanism of particle removal, where a particle is denied access through a pore or passageway that is smaller than the particle itself. Cathode sieving itself means that the particle of the cathode is removed down to a low level. The sieving process for the cathode is to get the smoothness level based on the specification needed.

Scaling Up Calculation

Scale-up is a distinct phase of company growth. It is a company that has achieved a lot, had some impressive success, and is ready to take it to the next level. Scale-up is not a simple linear increase in size, but also must maintain the identical product quality.

A similar result of the product quality but on a larger production scale.

While scaling up, there are so many ways of processes to produce the product, and each one of the processes and methods has different challenges that we need to consider when producing the product with the requirements needed[15]–[17]. By scaling up the company, surely the company needs to upgrade its production processes by using more advanced technology and machines for larger production quantities[15], [18], [19].

The result of calculation on scaling-up cathode production for this study covers raw material cost, machinery cost, labour cost, and operational cost. However, this paper only provides in detail on machinery cost, labour cost and operational cost. While the raw material cost will be explained in the other manuscript.

The raw material quantity needed is achieved from the amounts of raw materials needed in the beginning of the process (Co-precipitation). The quantity of materials is calculated to fulfil the production target which is 100 kg per batch with continuous production. The raw materials will cost USD 704,648.85 per year or USD 58,720.70 per month. On the Indonesian currency, it will cost IDR 880,810,559 monthly or IDR 10,569,726,719 yearly.

Machinery Cost

There are 26 items that will be used in the cathode process. These items contain the main machine for each process and the supporting tools. The first step is to weigh the raw materials, such as nickel sulphate, manganese sulphate, etc. This process will need a scale to weigh the raw materials as required. The scale needs to be used for weighing 300 kg of raw materials which estimated cost about IDR 2,850,000.

Moving on to the next process, co-precipitation. This process needs 16 items such as two stirred mixers for MSO_4 and NaOH with 800 Litre capacity with the price of IDR. 25,745,850. The material for these two mixers needs to be stainless steel tank with the mixer. The first tank will mix the MSO_4 such as nickel, manganese, and cobalt sulphate solution and the second tank will mix the NaOH precipitant solution such as natrium hydroxide, and ammonia.

Next, the storage tanks for the 2 mixers above is needed. The storage tanks are for MSO_4, NaOH with 2000 litre capacity. These storage tanks do not need to be made from stainless steel material. These storage tanks can use plastic material because it is cheaper compared to stainless steel ones. These storage tanks cost about IDR 3,100,000 each. At the same time, the storage tank for the NH_3 or ammonia with capacity 250 litre is needed. It is estimated the cost around IDR 350,000. The material for ammonia storage tank that can be used is plastic instead of stainless steel due to its cheaper price.

The most important machinery in the co-precipitation process is the CSTR or Continuously Stirred Tank Reactor. This reactor tank is responsible for mixing the MSO_4 solution and the NaOH solution together. This reactor tank needs to have a mixer and a heating rod because the mixing process needs to be at 60°C and double layered with a heating jacket. This reactor tank needs to be custom made. This reactor tank costs about IDR 108,634,500 and its custom made from Alibaba Exclude the shipping cost FOB from Qingdao. The cost for shipping is about IDR 4,060,000 from Qingdao Port to Tanjung Priok Port. So, the total cost for the reactor tank is IDR 112,694,500.

Besides that, this reactor process also needs one stirred tank slurry storage with at least 1600 litre. In the marketplace like e-commerce the 1600-liter storage tank is not common, so it is decided to use the 2000 litre for the price of IDR 8,000,000. This storage tank is made from stainless steel. So, this is the last main machinery for the co-precipitation process. But this co-precipitation process also needs a lot of supporting machinery such as pumps, water distillers, nitrogen generators, and nitrogen tanks.

The first supporting machinery for the co-precipitation process is the three peristaltic pumps for MSO_4 (from the mixer tank to the reactor tank), NaOH (from the mixer tank to the reactor tank), and NH_3 (from the Ammonia storage tank to the reactor tank). This process cannot use an ordinary pump because of the high stream needed. So, this process has to use the peristaltic pump. These peristaltic pumps each cost IDR 7,000,000 and the total price for the 3 pumps is about IDR 21,000,000. These pumps will be used to pump the MSO_4, NaOH, and NH_3 to the reactor. These peristaltic pumps will stream 467 ml/minute.

This co-precipitation process also needs a lot of supporting substances such as demineralized water and nitrogen. To produce 100 kg of cathode per cycle (24 hours), it is needed approximately 1100 litre of distilled water. Therefore, this process needs a water distiller with a capacity of at least 50 litre per minute. According to market research, the type of 50 litre per minute water distiller is not available. The closest one is a type with a capacity of 20 litre per minute and 10 litre per minute. Therefore, this process needs 2 water distillers with 20 litre per minute capacity and 1 water distiller with 10 litre per minute capacity. The 20-litre water distiller cost IDR 21,430,000 and the 10-litre water distiller cost IDR 11,560,000. Hence, the total cost for the water distiller is about IDR 54,500,000.

These water distillers also need a storage to store the water needed. Because each production process uses about 1,100 litres of water, the storage for the distilled water must contain at least twice the production usage or about 2,200 litres. The 2,200 litres tank storage for the distilled water cost about IDR 3,700,000. To pump the distilled water from the storage tank to the mixer tanks, two pumps are needed. The specification needed for these pumps is 55 litre per minute. The total cost for the distilled water pumps is IDR 2,000,000.

Besides demineralize water, this Co-Precipitation process also needs a constant flow of nitrogen (N_2) air in the reactor tank. The nitrogen generator is needed to produce or stream nitrogen for 70 L/minute. That is the amount of nitrogen needed in the reactor tank to replace all the oxygen in the tank so there will be no oxidation in the material. This nitrogen generator costs IDR 14,300,000. The nitrogen generator also needs storage to store the nitrogen. This storage needs to accommodate the need for N_2 in the co-precipitation process. This storage has a capacity of 6000 L. The N_2 storage tank costs IDR 1,700,000.

The third process is filtering. The filtering process will use a filter press to filter precipitant and to lower the conductivity scale. This process will filter 84 kg of cake per cycle. The 84 kg comes from the amount of material left after the filtering process. The material left in after the filtering process is 113.42 kg of $M(OH)_2$ and 54.1 litre of H_2O. Therefore, the total weight of the material is around 167.5 kg. Because this process only takes about 3.5 hours, we can have 2 filtering processes in 1 day. The capacity required by the machine can be divided in half (from the 2-filtering process in 1 day.) Therefore, it is needed a machine with the capacity of processing about 84 kg of material. One of these machines can process up to 50 kg of material in 1 cycle of filtering. So, in order to process 84 kg of material 2 machines will be needed. Each machine costs IDR 65,000,000 and an extra IDR 1,000,000 for the delivery cost. In total, this machinery costs about IDR 132,000,000. The filtering process itself aims to reduce the conductivity, then also to reduce the precipitation from the previous process[13], [15], [20].

The fourth process is drying-up the precursor. This process will use an oven to dry the precursor. The total material volume to put into the oven is 102.45 litre of slurry like material. It comes from 113.421 kg of $M(OH)_2$ which translates to 48.34 litre of volume and 54.1 litre of H_2O. The slurry like material is going to be put into a tray. The tray has a size of 72cm x 72cm x 10 cm, but the tray only be filled up to a height of 5 cm. Therefore, each tray can hold up to 25.92 litre of slurry-like material. To accommodate the 102.45 litre of slurry like material, 4 trays will be needed. So, the inner size of the oven must at least be 1 meter x 1 meter x 0.8 meter in order to fit all the tray properly[14], [15]. The oven needs to be customized to a size of 1 x 1 x 0,8 meters (800 L) to accommodate all the slurry like material which is divided in 4 trays. Besides that, the oven also needs to be able to produce heat around 80-120°C. This oven uses about 6,400 watts of electricity. The oven costs about IDR 13,200,000.

The fifth process is mixing the dry precursor with a ball mill. The type of grind in this process is dry grinding. There are 3 materials that will be grinded. The First one is LiOH, the second one is dry precursor and lithium, and the third one is mixing the cathode. This process will use a 100 and two 200 Litre roller ball mill to mix the dry precursor. 1 Ball mill (LiOH) for 100 kg (around 40 L) and 2 ball mills for 200 kg (around 80 L) with a density of 2.5 g/cm^3. This roller ball mill is made of zirconia with 180 Kg matching zirconia ball for the total price of IDR 453,995,000. The second ball mill has less volume which is 100 litre of the same materials and costs about IDR 216,050,000. These machines are imported from China, Xia Men port, so the price been told before was not include the shipping costs, taxes, etc. With the shipping cost and taxes, the total cost of these machines is IDR 1,319,186,800.

Moving on to the next process, calcination. Calcination needs a furnace to remove volatile substances, oxidize a portion of the mass, or render them friable. The furnace needs to have a capacity of 5030 L and a maximum temperature of 1,200°C. The furnace must be sufficient to accommodate the material from the previous ball milling process. the material that comes out of the ball mill process is as much as 163 kg. However, the furnace must be able to process 2 times that amount in order to save the use of the furnace because the furnace requires a large amount of power to operate. The material that is going to be put in the furnace must be put into a crucible measuring 167 mm x 167 mm x 81 mm. One crucible can hold up to 1.96 kg of material. So, to load all the material, 167 crucibles are needed. Thus, it takes a volume of 3,773 litres to enter the entire crucible into the furnace. Because in one furnace the maximum volume that can be used is only 80%, a furnace with a volume of 4,716 litres is needed. Such model will consume approximately 600 kW of electricity. The cost is estimated around IDR 15,000,000,000.

The last process is sieving. This process will use a vibrating sieve. This vibrating sieve has a 600 mm diameter with a double layer on the back to sieve the cathode and will use a power of 0.55 kW. For this process, it will take about 100 kg of cathodes and by that amounts of cathodes this machine can accommodate 25 kg of cathodes equals to 10 litre of cathodes and this machine will be used for 4 cycles. This machine is imported from China, Xinxiang Dayong Vibration Equipment Co., Ltd. It cost IDR 20,482,500 for the total amount of price of this machine, including shipping cost and taxes. The actual price of this machine is IDR 17,250,000 and for the shipping cost around IDR 300,000. For tax matters amounting to IDR 20,482,500. Table 1 gives a complete information about the total cost of machinery, equipment and its specification.

Table 1. Machinery Cost

Equipment	Specification	Cost (IDR)
Scale	300 kg capacity maximum	3,000,000
Stirred Tank-MSO_4 (Mixer 1)	800 L	25,745,850
Stirred Tank-NaOH (Mixer 2)	800 L	25,745,850
Storage Tank-MSO_4 (Storage Mixer 1)	2000 L	3,100,000
Storage Tank-NaOH (Storage Mixer 2)	2000 L	3,100,000
Storage Tank-NH_3	250 L, 6 production cycle	350,000
Storage Tank-Slurry	1600 L	8,000,000
Stirred Tank-Reactor	V=1,600 L, SS304, double layer jacket	108,634,500
Pump-MSO_4 to Reactor	Peristaltic, min 900 ml/minute	7,000,000
Pump-NaOH to Reactor	Peristaltic, min 900 ml/minute	7,000,000
Pump-NH_3 to Reactor	Peristaltic, min 900 ml/minute	7,000,000
Water Distiller	50 L/ minute	54,500,000
Distil Water Storage	2,200 L	3,700,000
Pump-Water Demineralized to Mixer 1	55 L/ minute	990,000
Pump-Water Demineralized to Mixer 2	55 L/ minute	990,000
Nitrogen Generator	70 L/ minute	14,300,000
Storage Tank-N_2	6,000 L	1,700,000
Filter Press	84 Kg cake per cycle	132,000,000
Oven	800 L (1 m x 1 m x 0.8 m), 5 Hz, stainless steel	13,200,000
Ball Mill-LiOH	100 Kg	216,050,000
Ball Mill-Li Mixing	200 Kg	453,995,000
Ball Mill-Cathode	200 Kg	453,995,000
Furnace	4,716 L, 1200°C maximum	15,000,000,000
Oxygen Generator	50 L/ minute	145,000,000
Storage Tank-O_2	6,000 L	1,500,000
Vibrating Sieve	4 Sieving cycles	20,482,500
Total		16,711,078,700

Table 2. Power Consumption

Equipment	Power (Kw)	Hour/Days	Quantity	Kwh	Days/Week	Kwh/Week
Stirred Tank-MSO4 (Mixer 1)	0.05	2	1	0.1	5	0.5
Stirred Tank-NaOH (Mixer 2)	0.05	2	1	0.1	5	0.5
Stirred Tank-Reactor	5.5	24	1	132	7	924
Pump-MSO4 to Reactor	0.04	24	1	0.96	7	6.72
Pump-NaOH to Reactor	0.04	24	1	0.96	7	6.72
Pump-NH3 to Reactor	0.04	24	1	0.96	7	6.72
Water Distiller	15	24	1	360	7	2,520
Pump-Water Demineralized to Mixer 1	0.2	0.5	1	0.1	5	0.5
Pump-Water Demineralized to Mixer 2	0.2	0.5	1	0.1	5	0.5
Nitrogen Generator	0.06	24	1	1.44	7	10.08
Filter Press	1.5	7	2	21	5	105
Oven	6.4	12	1	76.8	5	384
Ball Mill-LiOH	0.75	8	1	6	5	30
Ball Mill-Li Mixing	0.75	8	1	6	5	30
Ball Mill-Cathode	0.75	8	1	6	5	30
Furnace	626	20	1	12,52	3	37,560
Oxygen Generator	2.7	20	1	54	5	270
Vibrating Sieve	0.55	8	1	5	5	22
Total Kwh per Week						41,907.24
Total Kwh per Year						2,179,176.48
Total Cost per Year				**IDR 2,429,216,189**		

Following the machinery cost, power consumption also needs to be considered for accommodating the whole production operation. Electrical power must be sufficient to power the entire machine. Electric power also affects the tariff that must be paid. The tariff that must be paid is in kWh unit. Table 2 shows the recapitulation of all the machinery that uses electricity and the total Kwh it uses.

It is recapitulated that the total power for running all machinery along entire production is about 41,907 kWh per week and 2,179,176 kWh per year. Referring the industrial electricity rate at IDR 1,114.74 per kWh, the total electricity cost per year is around IDR 2,429,215,189.

Labour Cost

The definition of labour cost is the sum of all wages paid to employees, as well as the cost of employee benefits and payroll taxes paid by an employer. It possibly can be considered to hire number of required workforces. Table 3 shows the estimated of labour that is needed for maintaining production line.

Table 3. Number of manpower estimation

Process	Manpower	
	Operator	Supervisor
Solution Preparation	2	1
Precipitation Reaction	3	
Precursor Washing & Drying	4	1
Lithium Mixing	2	
Calcination	1	1
Sieving	2	
Total	14	3

In total, there are 14 operators and 3 supervisors that is needed for operating all the machinery and equipment in order to produce the NMC 811 cathode. In the first process, which is the solution preparation, 2 operators are needed because there are many types of material that need to be weighed and need to be put in the mixer tank. In the precipitation process, 3 operators needed to supervise the precipitation reaction process. Because this process runs 24/7, each operator needs to supervise for 8 hours per shift. So, in one day there are 3 shifts to keep the precipitation reaction process running. There will be one supervisor to supervise the solution preparation and precipitation reaction.

The precursor washing and drying process needs 4 operators to run all the machinery. This process uses 2 filtering machines, and each machine needs 2 operators to run it. So, in total precursor washing and drying process needs 4 operators. The operator is also in charge of putting the material into the oven after the washing process.

In the Lithium Mixing process, 2 operators are needed. There are 3 main job description of this mixing process which is ball milling the dry precursor after the drying process in oven, mixing the lithium with the precursor. In the calcination process, only one operator needed to man the machine. The operator is in charge of putting the material in the oven and supervising the calcination process. In sieving process, 2 operators are needed. The sieving process takes 2 hours for each cycle. So, in one day there will be 4 cycles of sieving. There will be one supervisor to supervise the calcination and sieving process. Table 4 shows the recapitulation of all the labour costs for a month and a year.

Table 4. Labour cost per month and per year

Role	Quantity	Cost per unit (IDR)	Monthly Total (IDR)	Yearly Total (IDR)
Supervisor	3	7,000,000	21,000,000	252,000,000
Operator	14	4,500,000	63,000,000	756,000,000
Total			84,000,000	1,008,000,000

Based on all of the calculation above, the total cost can be projected by adding material cost, machinery cost including power consumption cost, and labour cost.

Referring to table 5, the total cost to produce NMC 811 cathode 100 kg per batch or about 3,000 kg per month and 36 Tons per year is estimated about IDR 30,718,020,608.

Table 5. Total Cost

Type	Cost (IDR)
Material Cost (per year)	10,569,726,719
Machine Cost	16,711,078,700
Labour Cost (per year)	1,008,000,000
Power Consumption	2,429,215,189
Total	30,718,020,608

CONCLUSION

The analysis and calculation on scaling up cathode production at National Battery Research Institute was successfully conducted through literature study, interview, and observation method. As a note, the specification of the cathode under study is NMC 811 with hydroxide as the precipitant. The data that has been obtained are scaling-up process for the first stage of battery production, raw materials, machinery, power consumption and manpower. By calculating all of the cost structure and scaling-up aspect on battery production, it can be estimated that the total cost to scale-up NMC 811 cathode production into 100 kg per batch are IDR 30,718,020,608. Within a month, the system possibly produces 3,000 kg of cathode active material or 36 Tons in year. For further research, it is suggested that the external aspect such as interest rate and investment trends need to be added into account for gaining more specific calculation cost.

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AUTHOR CONTRIBUTION

R. A. F. Ramdhan, H. M. Ekaristianto and Y. D. Goenawan equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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