

Techno-economic analysis for the production of LaNi₅ particles

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Abstract

LaNi₅ is widely used in various applications. Many methods to produce LaNi₅ particles have been reported but information for the large-scale production, so far, is less available. This study aimed to evaluate the project for the production of LaNi₅ particles using combustion-reduction (CR) and co-precipitation-reduction (CPR) methods based on engineering and economic perspective. Engineering evaluation was conducted by evaluating the CR and CPR processes from stoichiometry. For the economic evaluation, several economic parameters were calculated in the ideal condition including gross profit margin (GPM), payback period (PBP), break-even point (BEP), cumulative net present value (CNPV), profitability index (PI), internal rate return (IRR), and return on investment (ROI). For the worst cases in the project, it was done by calculating both the internal problems (i.e., raw materials, sales, utility, labor, employee, fixed cost, variable cost, and production capacity) and the external issues (i.e., taxes and subsidiaries). The engineering analysis provided the information that CR and CPR projects are prospective for being able to be done using commercial apparatuses. The economic analysis from GPM, PBP, BEP, CNPV, and PI showed the positive results, while IRR and ROI showed the negative ones, indicating that the projects are acceptable for large-scale production, but it seems to be less attractive for industrial investors. The analysis also confirmed that the CR process was more prospective than the CPR process. This work has demonstrated the important of the projects for further developments.

Keywords: Techno-economic analysis; feasibility study; large-scale production; LaNi₅

1. Introduction

Lanthanum nickel (such as LaNi₅) materials are the attractive materials due to their wide applications, such as in hydrogen storage applications, catalysts in the synthesis process of materials (methane and carbon nanotubes), hydrogen purification, accumulation of heat and heat pump, refrigeration, actuator, and compressor[1].

Table 1 presents the summary of current reports to synthesize LaNi₅ materials. Many methods are available, and combustion-reduction (CR) and co-precipitation-reduction (CPR) methods have been found at the best. The methods allow the product with high purity, smaller sizes, excellent performance (i.e. faster kinetics, higher capacities, long-term cycling stability), less usage of raw materials, as well as the lower temperature process compared to other methods[2]. However, the methods are reported in the lab-scale work only. Since no information is available for the large-scale production, the work aimed to realize the mass production that can be used for commercialization. Hence, it will be interested for supporting industrial practitioners, especially in the optimization of the process [3].

To estimate the feasibility of large-scale production of

materials, techno-economic analysis (TEA) was used. Many works regarding TEA [4-11] have been reported (Table 2), showing the important role of TEA in estimating the feasibility of the production of materials in large scale. However, reports regarding TEA - especially for the production of materials for hydrogen generation and storage applications such as DeSantis et al. [4]) - are limited so far. The reports also have limitations in the complete economic parameters without providing a report of several cases that can significantly affect the project from the economical perspectives. In fact, information for large-scale production from whole perspective and parameters is important.

The purpose of this study was to report TEA for the production of LaNi₅ particles. In this study, we calculated the LaNi₅ production with the production capacity of 2.9 ton/year in ideal condition. The main reasons of the TEA for the production of LaNi₅ are:

- (1) Lanthanum-typed materials are very suitable to be developed in Indonesia. Lanthanum is one of the most common rare earth elements in Indonesia. This metal has been exploited since the last 20 years with a refined tin production capacity of 30,000 tons/year[12]. This material reserves in Indonesia more than 951,000 tons[13].
- (2) The use of rare earth elements in Indonesia has not been

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optimally utilized, while the use of lanthanum in the electric vehicle industry is recently increasing. Lanthanum is one of the less expensive alternative materials for neodymium[14].

(3) Intermetallic LaNi₅-based materials are the most rugged

materials and mainly used as the negative electrode in nickel-metal hydride (NiMH) batteries, which are produced and sold in more than 5 billion batteries per year.

Table 1. Current reports on the LaNi₅ synthesis methods

| Product size (μm) | Raw materials | Method | Synthesis condition | Reference |
|-------------------|---|----------------------------|---------------------|-----------|
| 10–20 | La, Ni | High temperature melting | – | [17] |
| 20–100 | Commercial LaNi ₅ | Mechanical milling | – | [18] |
| 40 | La(NO ₃) ₃ , Ni(NO ₃) ₂ | Combustion-solid reduction | 600°C | [19] |
| 30 | La ₂ O ₃ , Ni | Solid reduction | 1500°C, 1 MPa | [20] |
| 0.20 | LaCl ₃ , NiCl ₂ | Co-precipitation-reduction | 1000°C | [21] |
| 0.17 | La(NO ₃) ₃ , Ni(NO ₃) ₂ | Combustion-reduction | 600°C | [2] |
| 0.25 | LaCl ₃ , NiCl ₂ | Co-precipitation-reduction | 600°C | [2] |

Table 2. Current reports on the techno-economic analysis in the production of materials

| Topic materials | Product | Main analysis | Reference |
|-----------------------------|---|---|-----------|
| Metal-organic frameworks | <ul style="list-style-type: none"> 50-2,500 tons/year via solvothermal method | <ul style="list-style-type: none"> Evaluating the cost impact of reducing solvent usage Identifying additional opportunities for achieving the expected production costs | [3] |
| Ammonia borane | <ul style="list-style-type: none"> 4,795.4 kg/year via sol-gel method | <ul style="list-style-type: none"> Optimizing the condition of process in the production of materials economically Predicting the production capacity with its manufacturing cost | [4] |
| Lipase enzyme | <ul style="list-style-type: none"> 365-3,650 kg/year via solid-state fermentation method | <ul style="list-style-type: none"> Proposing the best conditions and designed equipment to produce the materials Evaluating the economic parameters | [5] |
| Chitosan | <ul style="list-style-type: none"> 12,152 tons/year via deacetylation method | <ul style="list-style-type: none"> Evaluating the economic parameters Evaluating the effect of changing raw materials costs | [6] |
| Lactic acid | <ul style="list-style-type: none"> 100,000 tons/year via fermentation method | <ul style="list-style-type: none"> Evaluating and improving the feasibility of the production Estimating the production capacity and costs with different fermentation pathways | [7] |
| Activated carbon and silica | <ul style="list-style-type: none"> 168-538 kg/year via burning and extraction method | <ul style="list-style-type: none"> Evaluating the economic parameters Analyzing the project from economics perspective in the ideal condition Performing the economics condition of the project in the circumstances that is out of the ideal condition in several cases | [8] |
| Titanium dioxide | <ul style="list-style-type: none"> 12 tons/year via liquid-phases synthesis method | <ul style="list-style-type: none"> Evaluating the economic parameters Analyzing the project from economics perspective in the ideal condition Performing the economics condition of the project in the circumstances that is out of the ideal condition in several cases | [9] |
| Silica | <ul style="list-style-type: none"> 135-360 tons/year via burning and extraction method | <ul style="list-style-type: none"> Evaluating the economic parameters Analyzing the project from economics perspective in the ideal condition Performing the economics condition of the project in the circumstances that is out of the ideal condition in several cases | [10] |

(4) The use of LaNi_5 materials is effective for catalysts in the synthesis process of materials (methane and carbon nanotubes). LaNi_5 also has good applications for hydrogen purification, accumulation of heat and heat pump, refrigeration, actuator, and compressor[1].

(3) LaNi_5 materials are easily converted into other materials such as metal oxide (La_2O_3 , NiO) and perovskite (LaNiO_3) through thermal decomposition. In addition, these materials can be converted into pure lanthanum and nickel through further process. Thus, the application of LaNi_5 can be used for further applications[15,16].

The above reasons make lanthanum to be one of the popular artists in the world[17], while the information for scaling-up production is still limited. The information on TEA of LaNi_5 will bring positive impacts on the understanding for the production of LaNi_5 particles. The production relates to the usage of large amount of lanthanum, and the main idea of this TEA is to find the best and optimum condition in the production, which can minimize the use of raw materials. Thus, this work compared two types of synthesis methods: CR and CPR methods and reported an engineering process design and economic evaluation in the large-scale production of LaNi_5 particles via both methods.

To support the analysis, this study used several economic parameters (i.e., gross profit margin (GPM), payback period (PBP), break-even point (BEP), cumulative net present value (CNPV), profitability index (PI), internal rate return (IRR), and return on investment (ROI)) in the ideal condition and the worst cases of the project. The worst cases were applied to the calculation based on internal problems (i.e., raw materials, sales, utility, labor, employee, fixed cost, variable cost, and production capacity) and external issues (i.e., taxes and subsidiaries). These analyses are essential to obtain information regarding the profitability of the process [18].

2. Materials and Methods

2.1. Theoretical Synthesis of LaNi_5 Materials

The LaNi_5 materials was produced by adopting CR and CPR as suggested by Liu and Aguey-Zinsou[2].

In the CR typical synthesis, lanthanum (III) and nickel (II) nitrate hexahydrate were mixed with glycine in a mole ratio of 1:5:7.2 and dissolved in distilled water under stirring for 1 h. The solution was evaporated at 100°C for 4 h. The combustion was ignited by increasing the temperature to 500°C and hold for 2 h. The heating process is important to remove water and convert some organic components [19]. Prior the reduction step, the obtained black powder was firstly mixed with CaH_2 and LiCl in a mass ratio of 1:2:0.9 and heated at 600°C . At this temperature, the powder was kept for 5 h and reduced under a H_2 flow. At the end process, byproduct materials were removed by suspending the resulting powder in an absolute ethanol saturated with ammonia chloride to obtain pure LaNi_5 . The suspension was stirred for 6 h, separated by centrifugation, washed with absolute ethanol and dried overnight.

In the CPR method, lanthanum (III) and nickel (II) chloride hexahydrate in a mole ratio of 1:5 were dissolved in a mixture of distilled water:acetone (volume = 2:1) under stirring for 1

h. Then, Na_2CO_3 was added dropwise into previous mixture until reaching $\text{pH} = 10$. It was continued by slowly adding NaOH solution until reaching $\text{pH} = 12$. Adding Na_2CO_3 and NaOH led to gradually form the precipitate. The solution/precipitate mixture was allowed to age at 40°C overnight. In this method, the reduction was carried out in two steps. In the first step, the precipitate was heated at a room temperature of 750°C and reduced for 5 h under a H_2 flow to obtain the intermediate. The obtained material was again reduced with CaH_2 as followed by the previous procedure, in the CR method, including the separating and washing steps.

2.2. Energy and mass balance

To design an engineering process and calculate mass balance easier for producing LaNi_5 on a large scale, the following assumptions were used in a stoichiometric manner in the calculation in both methods[20,21]:

- (i) The cost of all apparatuses was based on commercially available online market;
- (ii) The compositions of the reactants, lanthanum: nickel nitrate/chloride were 1:5 mole ratio;
- (iii) All reactants were consumed perfectly. There were no byproducts produced and reactants remained;
- (iv) The reduced mass (as mass losses) of the materials was 5% in each process;
- (v) The temperatures in each process were based on reference [2];
- (vi) The conversion rate of LaNi_5 production was 80%;
- (vii) The final products were LaNi_5 materials only;
- (viii) In one-day process, the total processing cycle was 1 cycle as well as 5 cycles/week.

Based on the energy and mass balance, in the baseline of 100%, all methods produced 12.08 kg of LaNi_5 in one cycle. Under an ideal condition, the project could be scaled up to 240 cycles in a year. As a result, the production capacity of the project is 2,899.20 kg/year or 2.90 ton/year.

2.3. Economic evaluation

To estimate economic evaluation parameters including GPM, PBP, BEP, BEC, IRR, CNPV, ROI, and PI, the data (price and specification) for the use of equipment, raw materials, and utility costs in the project were used as per obtained from available online shopping websites. The following economic evaluation parameters were calculated through simple mathematical equations based on references [9,11,27].

- (i) GPM (IDR/pack) was calculated by reducing sales and raw material costs.
- (ii) PBP (year) was life time point (y axis) when CNPV/TIC (x axis) equaled to zero.
- (iii) BEP (pack) was calculated by dividing fixed costs against sales with variable costs difference.
- (iv) BEC (%) was calculated by dividing BEP with production capacity over a period of time.
- (v) IRR (%) was calculated through Equation (1) as follow:

$$IRR = \sum_{t=1}^t \frac{C_t}{(1+r)^t} - C_0 \quad (1)$$

where:

C_t = net cash inflow during the period of t

r = discount rate

t = number of time periods

C_0 = total initial investment cost

- (vi) CNPV (%) was obtained from NPV at specific time. In short, it was by adding up NPV from the initial establishment of a project. NPV could be obtained by multiplying cash flow with discount factor.
- (vii) ROI (%) was calculated by dividing gained total profits with investment costs.
- (viii) PI (%) was calculated by dividing sales and manufacturing costs difference with sales (profit-to-sales) or investment (profit-to-TIC).

The following assumptions were needed to determine the parameter values in the ideal condition:

- (i) The calculation used fixed currency on the conversion of 1 USD = 15,000 IDR;
- (ii) For CR method, the prices of $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$, $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, glycine, calcium hydride, and lithium chloride per kg were 450,000; 570,000; 502,500; 1,102,500; and 180,000 IDR; respectively. The prices of distilled water, ethanol (96%), ammonium chloride, and hydrogen gas per liter were 5,400; 60,000; 15,000; and 189,900 IDR; respectively;
- (iii) For CPR method, the prices of $\text{LaCl}_3 \cdot 6\text{H}_2\text{O}$, $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$, sodium carbonate, sodium hydroxide, calcium hydride, and lithium chloride per kg were 630,000; 489,000; 3,750; 19,350; 1,102,500; and 180,000 IDR; respectively. The prices of distilled water, acetone, ethanol (96%), ammonium chloride, and hydrogen gas per liter were 5,400; 100,000; 60,000; 15,000; and 189,900 IDR; respectively;
- (iv) Labor wages were 48,000,000 IDR per employee per year;
- (v) Total number of employees working for the project were 20 people;
- (vi) The project has been being operated for 20 years;
- (vii) Utility costs that must be paid per year are 607,007,617 and 692,327,617 IDR for CR and CPR methods, respectively;
- (viii) One product containing LaNi_5 materials was packed in 50 grams and the price was 2,250,000 IDR per pack;
- (ix) The discount rate was 15%;
- (x) The income tax was 10%;
- (xi) Total investment cost (TIC) was calculated based on the Lang Factor[27];
- (xii) Direct-type depreciation was used to calculate depreciation.

2.4. Parameters in the economic evaluation

To ensure the feasibility of the projects, the economic

condition was changed from an ideal condition to the worst cases. Several cases were applied to the calculation by manipulating some internal problems such as raw materials, sales, utility, labor, variable cost, fixed cost, and production capacity, as well as external issues such as taxes and subsidiaries. The manipulated internal and external issues were investigated and used as the basic points:

- (i) Raw materials, sales, utility, and labor were varied from -100% up to 300%.
- (ii) Fixed cost was varied from 50% up to 200%.
- (iii) Variable cost was varied from 50% up to 150%.
- (iv) Number of employee was varied from 100% up to 200%.
- (v) Production capacity was varied from 85% up to 100%.
- (vi) Taxes and subsidiaries was varied from -50% up to 90%.

3. Results and Discussion

3.1. Engineering Perspective

Fig.1 shows the engineering process design in the large-scale production of LaNi_5 materials via CR and CPR methods. All precursors in both methods were easily dissolved in distilled water due to their chemical properties as nitrate and chloride salts. The project for CR method needed a fuel, i.e. glycine, to ignite the combustion occurred in the process when the temperature raised to 600°C in the calciner. On the other hand, CPR needed precipitating agents, i.e. Na_2CO_3 and NaOH , to yield a precipitate in the reactor. The fuel and precipitating agents were added in the reactor.

Referring to the type of the reactor needed, the reaction in both methods worked in a 1.00 m^3 semi batch-type reactor with featuring of an aluminum silicate insulator and propeller top centre-entry agitator system. This system was used for the mixing process to create restrictive conditions in which the solution was homogenous. The semi batch-type of reactor supported the reactants to first add to form a precursor solution before being added continuously precipitating agents during operation. This operating model was used desirably to maintain a low concentration of one reactant (the injected reactant)[28] and to prevent the formation of byproducts[20]. Furthermore, the reactor increased the selectivity of the desired product and supplied or removed heat by injecting an inert species.

In the separator, the materials were separated using a fluid-solid separation operation by the centrifugation method. The centrifugation was very effective in increasing sedimentation rates, particularly for the very small particles (<10 mm) in which the liquid was very viscous and the differences in density between particles and liquids were very small[29]. The materials were fed into the drum through the feeding pipe on the hermetic closure casing and rotated by a centrifuge device. Then, the solid phase was stopped at the filter layer. Meanwhile, the undesired liquid phase was removed under the action of the centrifuge force field and passed through the filter media to discharge out of the machine. This separator featured with an ethanol washing system so the solid phase was maintained in the drum and washed with ethanol. The solid could be pushed into pipes to be distributed in the next process.

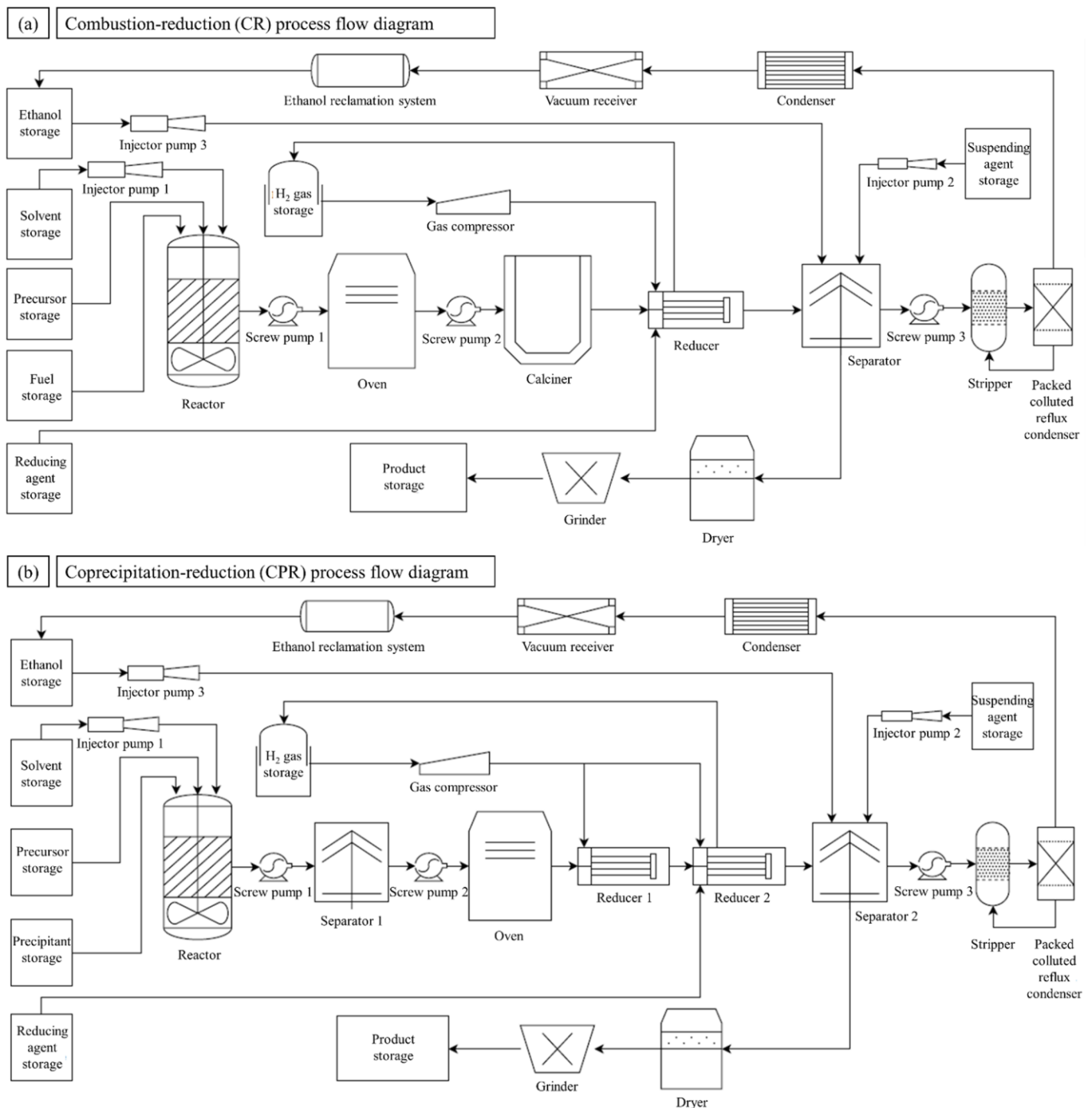


Fig. 1. Engineering process design in the large-scale production of LaNi_5 materials via (a) combustion-reduction (CR) and (b) co-precipitation-reduction (CPR)

The large-scale production of LaNi_5 materials via CR and CPR methods has been calculated stoichiometrically for industrial scale [11]. All methods produced 12.08 kg of LaNi_5 in one cycle. If the product consists of 0.05 kg of LaNi_5 materials per pack, there will be about 242 packs/cycle. From an engineering point of view, this result is very prospective. In addition to the scaling-up process that can be carried out using commercial equipment, the use of solvent such as distilled water is very likely to be done in the industrial scale. Under an ideal condition, the project can be scaled up to 240 cycles and produce more than 57,972 packs/year. Furthermore, a cost analysis of the total equipment per batch requires a total equipment purchase cost of 3,862,500,000 and 3,757,500,000

IDR for the CR and CPR, respectively. When added with the Lang Factor into the calculation, the TIC values were around 17,149,500,000 and 16,683,300,000 IDR; respectively. These values are relatively economical for producing LaNi_5 materials made from rare earth metals.

3.2. Ideal Condition

Fig. 2 illustrates the ideal condition of CNPV/TIC (%) against the life time for CR and CPR methods. The initial time showed the negative value of CNPV/TIC in the range of zero to the third year. The value started to increase with the increasing project time since the third year. All projects are

able to still run up to more than 20 years. The CR scheme was found to get the higher final CNPV/TIC and faster profitable compared to the CPR.

Table 3 presents the economic evaluation parameters including GPM, PBP, BEP, BEC, IRR, CNPV, ROI, and PI. The decreases in CNPV/TIC in early years were caused by the start-up fee at the beginning of the project, while the curves started to increase since the production process began in the third year. Several factors affecting this result included the variable costs, fixed costs, sales, depreciation, pre-tax profits, and income taxes that started to consider in the third year. As shown in the curve, different trends occurred significantly in each project of methods due to different variable costs and

fixed costs. The higher costs of raw materials, utilities, and equipment to produce LaNi₅ materials via CR made its curve line longer to reach the payback, CNPV/TIC = 0.

Generally, the values of GPM, PBP, BEP, BEC, final CNPV/TIC, and PI were positive, while other economic parameters (IRR and ROI) were negative. Although the project under the ideal condition was prospective, the negative parameters indicated that the project seemed to be a less attractive for industrial investors. This perspective is based on the standard capital market in Indonesia. For further details, the analysis of any parameters in the ideal case is discussed as follows.

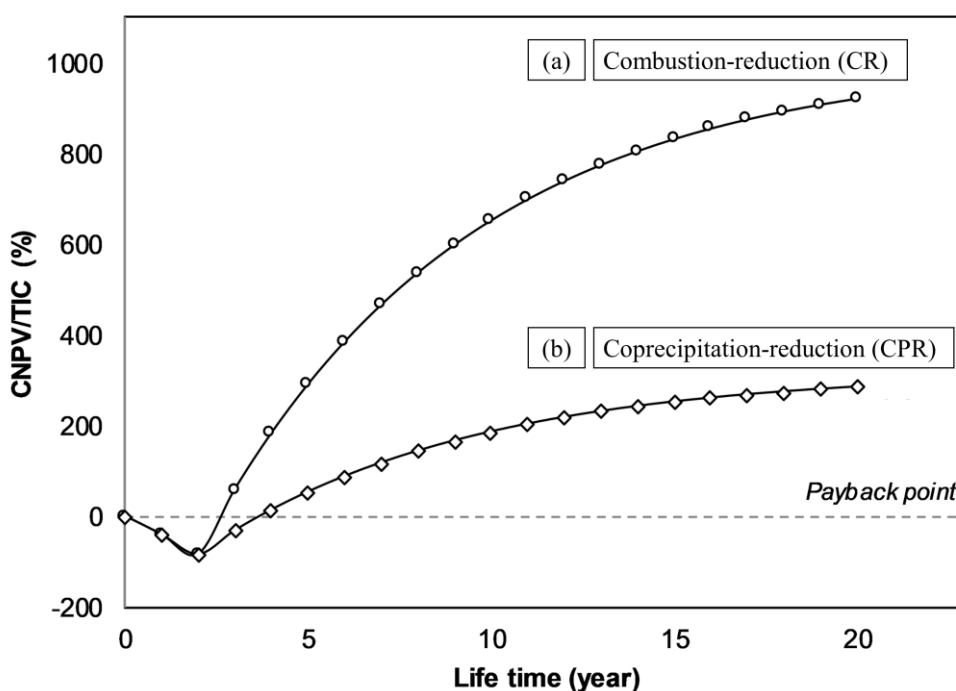


Fig. 2. Ideal condition in the production of LaNi₅ materials via (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR) for CNPV/TIC (%) to life time (year)

Table 3. Summary economic analysis reports of LaNi₅ using combustion-reduction (CR) and coprecipitation-reduction (CPR) methods

| Economic evaluation parameter | Combustion-reduction | Coprecipitation-reduction |
|-------------------------------|----------------------|---------------------------|
| | Value | |
| GPM (IDR/pack) | 979473 | 519456 |
| PBP (years) | 2.59 | 3.70 |
| BEP (packs) | 5282 | 12494 |
| BEC (%) | 9.11 | 21.55 |
| IRR (%) | 131.02 | 59.99 |
| Final CNPV/TIC (%) | 922.08 | 284.21 |
| ROI (% per year) | 13.63 | 5.13 |
| Total ROI | 245.30 | 92.34 |
| PI profit-to-sales (%) | 32.25 | 11.81 |
| PI profit-to-TIC (%) | 245.30 | 92.34 |

In short, GPM analysis determined the profitability of the project. The project of both methods in this work showed a moderate benefit, whereas the CR method had a greater

benefit compared to CPR. The difference of their GPMs was almost two times. The expected profitable in selling product of CR and CPR was more than 40 and 20%, respectively,

when the project charged the product by 2,250,000 IDR/pack. This result confirmed that GPM showed positive. Although GPM analysis indicated profitable project, there were such other basic economic evaluation parameters [9,11].

The result of PBP analysis showed that the project was able to get payback after working in 2-4 years. The CR scheme got payback faster once the CPR was almost a year slower. The investment of more than 1,000,000 USD within 2-4 years was considered sufficiently short; thus, it showed a quite competitive condition even if compared to the standard capital market. The standard capital market in Indonesia for investing is 1,000,000 USD that commonly promotes PBP around 40 years.

In the economic analysis, BEP value estimates the amount of minimum product that must be sold to cover total production costs, while BEC is its percentage of minimum product compared to total production capacity in a year. This analysis shows that the total product of LaNi_5 materials via CR and CPR must be sold out per year at least 5,282 and 12,494 packs; respectively. The values are relatively easy to market the product during a year. Once the number of products that are ready to market in the ideal condition are 57,972 packs/year, it promotes BEC at least 9.11 and 21.55% of available CR and CPR products, respectively that must be in market to cover total production costs.

IRR analysis in this ideal condition showed the value of 131.02 (CR) and 59.99% (CPR) for 20 years by only 2-6% per year. Since this value measured an indicator of efficiency level from an investment, the calculation of this analysis gave a very low rate. However, an investment for project can be accepted when the IRR is greater than IRR investing in other places such as deposit rates. The values indicate that the IRR

is not promising and creating conflicts against Indonesian local bank interest of about 5-6% [9].

The final CNPV/TIC analysis showed a positive result. This result seemed very high for the project to run for 20 years. The project always gets more additional benefits than the invested funds. In addition, the final CNPV/TIC showed that CR scheme is significantly more promising than CPR.

ROI analysis showed a negative result with a value of around 5-14%. Compared to bank interest and capital markets, the additional benefits are relatively less attractive. The local capital market in Indonesia should be at least 10% of profit/year in which 2.5% of it is usually used for *zakat* [9]. In short, investing fund of 100 USD, for example, generates additional benefits of only 5-14 USD.

PI analysis is a way to identify a relationship between costs and impacts of a project. This analysis, i.e. PI profit-to-sales and PI profit-to-TIC, showed some positive results in which the product via CR had the best result for creating a good impact on sales and investment costs of the project. That result indicated the sufficient prospective of the project.

Based on the discussions, the analysis concluded that the product of LaNi_5 materials via CR was found more prospective in all of economic parameters rather than via CPR. The result of economic evaluation showed a sufficient prospective but unattractive for industrial investors in Indonesia. However, other perspectives must be considered and the negative economic parameters need to be further evaluated. The new idea in this research is intended to provide information and knowledge about the feasibility in the production of LaNi_5 materials for the industrial practitioners to consider.

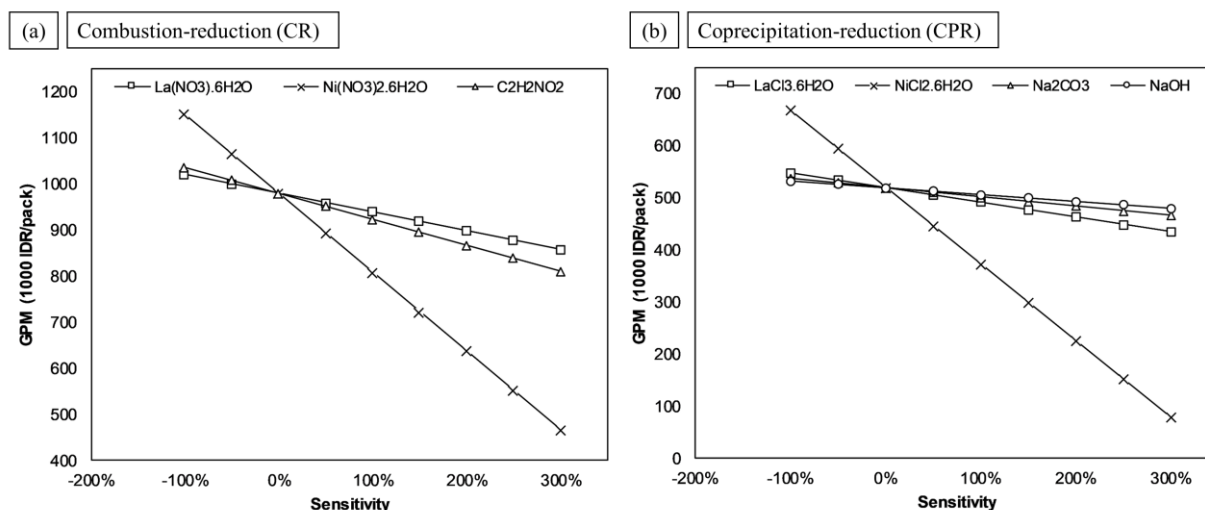


Fig. 3. Effect of changing raw materials (reagents) to the GPM for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR)

3.3. Internal Issues: Changing raw materials, sales, labor, and utility

Figs. 3, 4, and 5 present the effects of changing raw materials and sales costs on GPM. In evaluating a project, the issues must be estimated for a specific amount because these costs varied with location. It is important in estimating benefits without exaggerating and losing credibility [30]. The purpose of positive analysis of changing cost is to investigate the impact whether the merchant rises the raw materials cost or the project increases the sales, while the negative is its

opposite. As shown in the curves, changing sales significantly affects GPM but changing raw materials is not. Increases in raw materials have impacts on the decreases in GPM in which the project suffers a loss. However, increases in sales made GPM more profitable. In this work, the raw materials consisted of reagents and reducing agents. We evaluated them separately considering that each method had different reagents and reduction steps.

Fig. 3 shows the result of changing all reagents' costs against the GPM. The CR scheme could maintain to get GPM more than 400,000 IDR/pack even if the cost increased up to

300%. This result was better than reagents of CPR where the GPM of $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ in the exception was less than 400,000 IDR/pack and even closer to GPM = 0.

Fig. 4 shows the result of changing reducing agents' costs against the GPM. The line in CPR is sharper than that of CR due to more consumed hydrogen in two reduction steps in CPR scheme, as described in engineering perspectives. This larger use of hydrogen increased the hydrogen costs and brought a significant effect on the GPM. The increasing cost up to 300% incurred the project to be loss. The rising should be kept at least 200% due to negative GPM in 300% for CR. The worst case was found in CPR where the cost could not maintain the rising of more than 50%.

Fig. 5 shows the result of changing sales costs. Rising sales led to getting higher GPM. If we did further analysis to increase the sensitivity, each line always showed a higher value, and the line for CR was always on the top of CPR. The price of 2,250,000 IDR was the optimum value in selling the

product per pack to get the project well. The curves show that the sensitivity of -50% even could not get the GPM > 0 for product of all projects.

The analysis of changing raw materials and sales concluded that the most influential parameters were found for controlling the hydrogen gas cost and maintaining the sales. To get the successful project, rising hydrogen cost should not be more than 200 and 50% for CR and CPR, respectively. The project should sell the product with the price of at least 2,250,000 IDR/pack. Furthermore, the product of CR still showed the better result in these cases.

Of other raw materials, the cost of hydrogen had a significant effect on the economic condition of the project. The best solution was by providing hydrogen gas provided from gasification and biomass [31]. In addition, the use of this type of hydrogen can give the benefits in terms of ecological and economics perspectives[32].

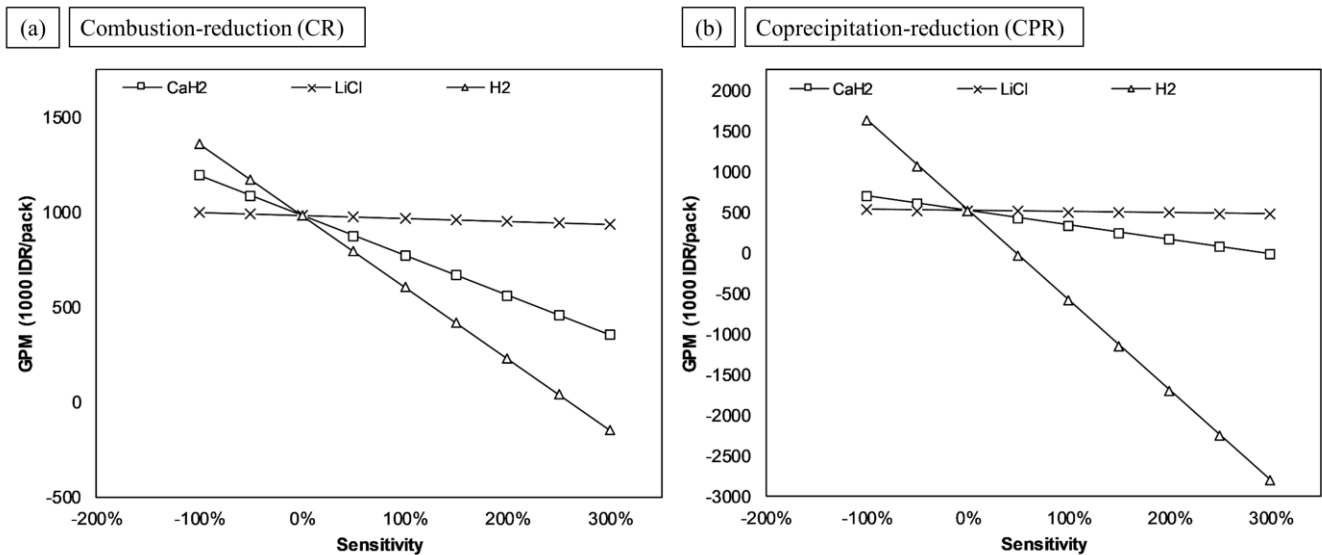


Fig. 4. Effect of changing raw materials (reducing agents) to the GPM for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR)

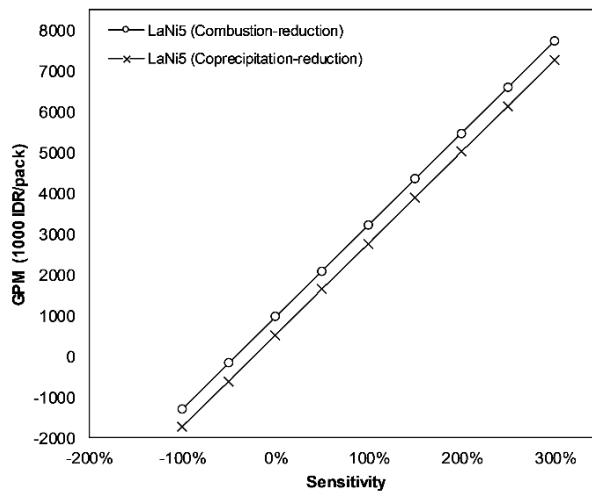


Fig. 5. Effect of changing sales (products) to the GPM for combustion-reduction (CR) and coprecipitation-reduction (CPR)

In addition to raw materials and sales, other factors influencing the economic condition in the project were utility

and labor. Figs. 6 and 7 describe the analysis of PI as a function of raw materials, sales, utility, and labor. In the same

correlation with the GPM analysis, changing these factors showed a similar trend. The sales factor had a positive correlation to the GPM, while the others were in the opposite.

In the case of PI profit-to-sales, the raw materials, utility, and labor showed the decreasing linear curves in relation with their increasing cost, while the sales had an opposite exponential curve. Changing utility and labor costs brought some impacts on the value of PI but less significant impacts compared to the changing raw materials and sales. Moreover, they could still maintain the positive PI even if the changing cost rose up to 300%. For product from CR, the positive PI could be achieved when the raw materials cost did not rise more than 50% and the sales did not change less than -25%. Nevertheless, the sensitivity of raw materials and sales could not be less than 0% for product of CPR to reach positive PI. Further increases in sales cost did not affect to the profit since the increases in sales were related to the change in variable cost[33].

In the case of PI profit-to-investment, all factors were found to be relatively straight-linear curves. Changing utility and labor costs of up to 300% could still achieve the positive PI in all projects. But, a problem in changing raw materials was found, in which they maintained only the rising cost up to 50% for CR and no less than 0% for CPR. Increases in sales

had a significant impact on the successful project. Based on the analysis, changing raw materials and sales was found as the most dominant factors to impact the value of PI.

To confirm the effect of raw materials, sales, utility, and labor on the profit, the analysis of BEP was conducted (see Fig. 8). Changing these factors from -100% to 300% confirmed the feasibility of the project, stating the condition in feasible (above the zero point) or non-feasible (below the zero point). As shown in an insert image in Fig. 8, increases in sales have a good correlation with decreasing BEP. Therefore, if the project increases the price of product, the amount of minimum product that must be sold to cover total production costs allowed decreasing. On the contrary, raw materials, utility, and labor had an opposite impact compared to the sales. The results showed that the project would be feasible when the factors were conducted in the specific range. Generally, changing utility and labor cost even up to 300% could still allow the project to be feasible for product via all methods. Specifically, the project was relatively in a non-feasible condition when the sale decreased more than -50% and an increase in raw materials of was more than 75% for CR. In the same condition, decreases in sales of down to more than -25% and increases in raw materials of up to 25% were not suggested for CPR.

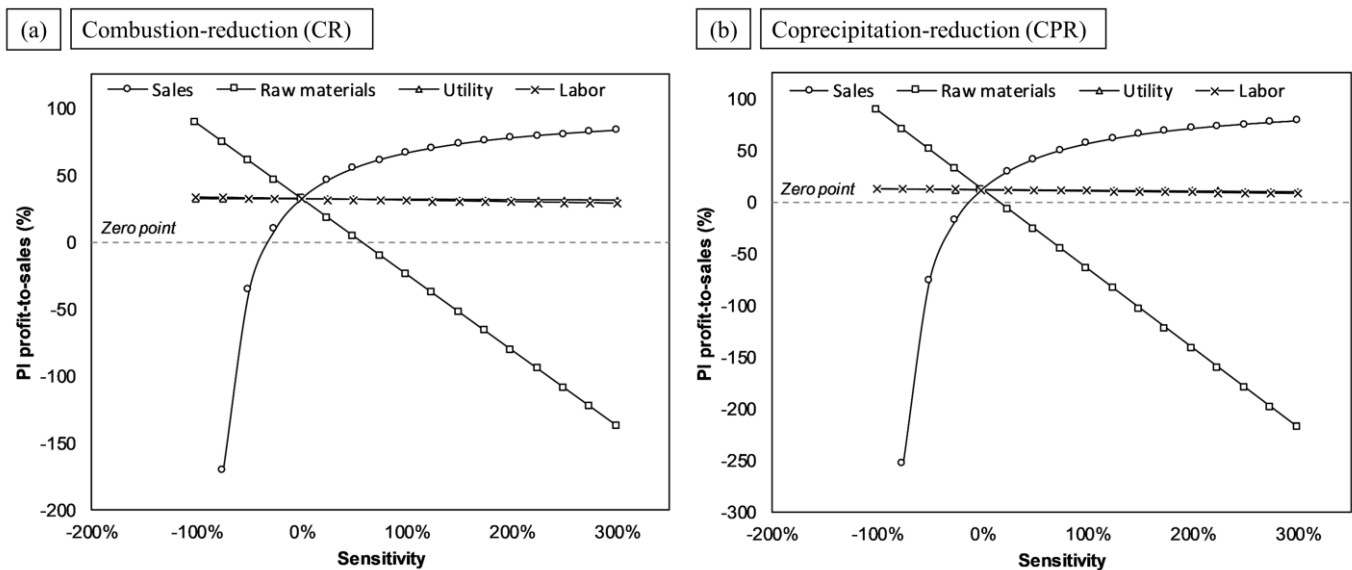


Fig. 6. Analysis of PI profit-to-sales as a function of sales, raw materials, utility, and labor for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR)

3.4. Internal Issues: Changing fixed costs and variable costs

Operational activity costs were classified according to their reaction to the changes of enterprise activities in which the costs were divided into two groups: variable costs and fixed costs[34]. Since fixed costs and variable costs started to consider in the third year whereas the time when the CNPV/TIC grew up and impacted on different trends in each project, the analysis of CNPV/TIC curve based on changing fixed costs and variable costs was investigated (see Figs. 9 and 10).

In Fig. 9, although the increases in fixed costs made the project a loss and the decreases got a benefit, the curve

showed no significant impact on the CNPV/TIC. It was because there were not many factors affecting to the fixed costs. The fixed cost only depended on the total price of apparatus and other capital-related cost including maintenance, operating supplies, environmental, local taxes, or insurance cost. Furthermore, the project of CR scheme had a better curve than CPR. However, the project of both methods was still able to maintain the profitable project even if the change raises up to two times of the fixed costs in the ideal condition (200%). This condition also brought an impact on PBP, as shown in an insert image in Fig 10. The increase in fixed cost delayed the payback but there were only a few months in every single 25% increases.

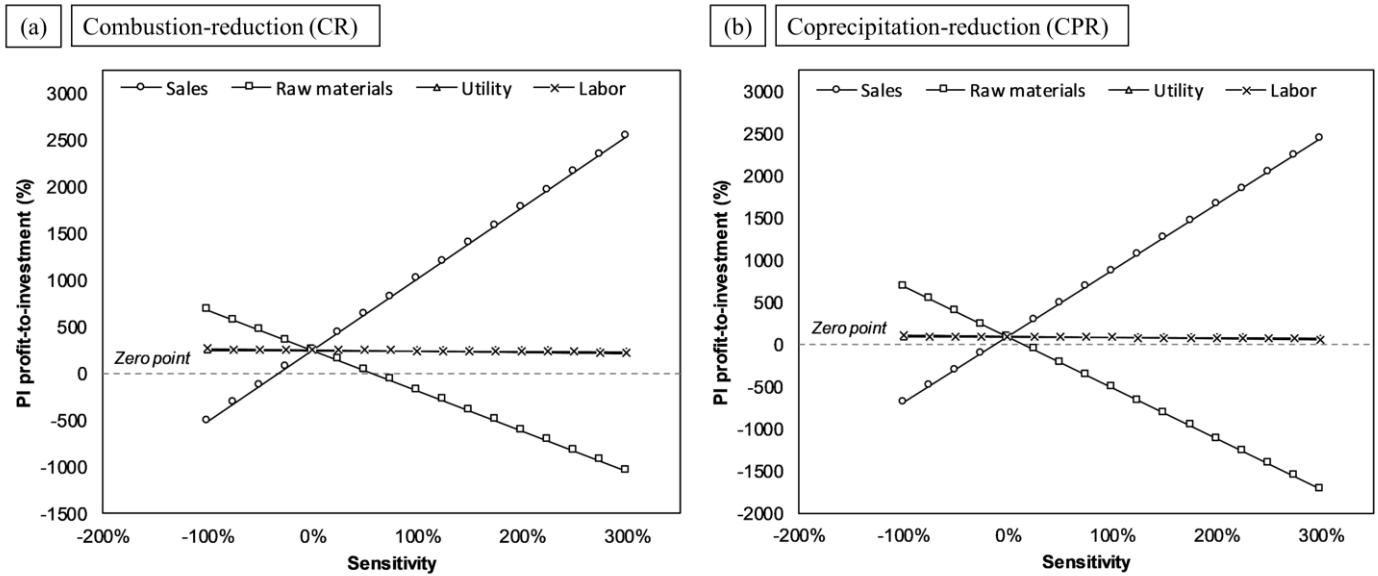


Fig. 7. Analysis of PI profit-to-investment as a function of sales, raw materials, utility, and labor for (a) combustion-reduction (CR) and (b) co-precipitation-reduction (CPR)

The significant impact on the CNPV/TIC was showed by changing variable costs. Raw materials, utility, and labor were the factors included in the variable costs. The variable costs reached a critical value to affect the profitability of the process[35]. Decreases in variable costs led to the high value for final CNPV/TIC, effectively generating more profit. Moreover, this condition also accelerated PBP, as shown in an insert image in Fig. 10. However, in the opposite condition, whereas the variable cost increased the project got less additional benefits than the invested funds and reached the payback longer. In Fig. 10, increases in variable costs up to 140% could still maintain the project to get payback for CR but it was only up to 110% for CPR. For more information, maximum variable cost of CR and CPR get the PBP of after 6.04 and 16.56 years, respectively. To be carefully noted, when the project used variable costs more than these maximum value, the PBP point could not be reached, creating the project unprofitable.

3.5. Internal Issues: Changing employee numbers

The number of employees on the project can be considered to prevent several possible problems. The possibilities that may occur on the employee themselves include illness, time off, or even death. By increasing the number of employees, these problems can be overcome at the time. Fig. 11 shows the analysis of CNPV/TIC curve based on the change of employee numbers. Although the increases in the employees got the project a loss, the curve showed that employee numbers did not bring any significant impact on the CNPV/TIC. The project of CR scheme showed a better curve than CPR. Furthermore, the project of both methods was still able to maintain the profitable project even if the employee

numbers increased up to two times of the total employee numbers in the ideal condition.

If the number of employees is decreased, the curve will show a faster payback. This is because the number of employees determines the labor cost, and the labor cost determines CNPV/TIC. However, when we decrease the number of employees, production capacity will be down. For instance, the productivity of the project is affected by the existence of the employee[36]. The small number of employees brings an impact on the fact that the plant cannot be operated.

3.6. Internal Issues: Changing production capacity

The changes in production capacity of the project could determine the cash flow of each scenario[34]. Finally, the cash flow affected the net present value (NPV) and gave the economic risk of the changes in each scenario. In the production capacity, the analysis could predict the required minimum capacity to make the project profitable. As shown in Fig. 12, production capacity plays some important roles to estimate in detail the profitable and the time to reach the PBP. From the curve, decreases in the production capacity affected very significantly to directly decrease the value of CNPV/TIC, influencing PBP. Decreases in the production capacity led to a low value for the final CNPV/TIC and slowed down the obtainment of the PBP, as shown in an insert image in Fig. 12.

In this figure, the minimum production capacity to sustain the project should be more than 70% for CR and 95% for CPR. When the project produced the product less than these minimum values, the PBP could not be reached, creating the unprofitable project. The minimum production capacity of CR and CPR can get the PBP of after 9.29 and 5.17 years, respectively.

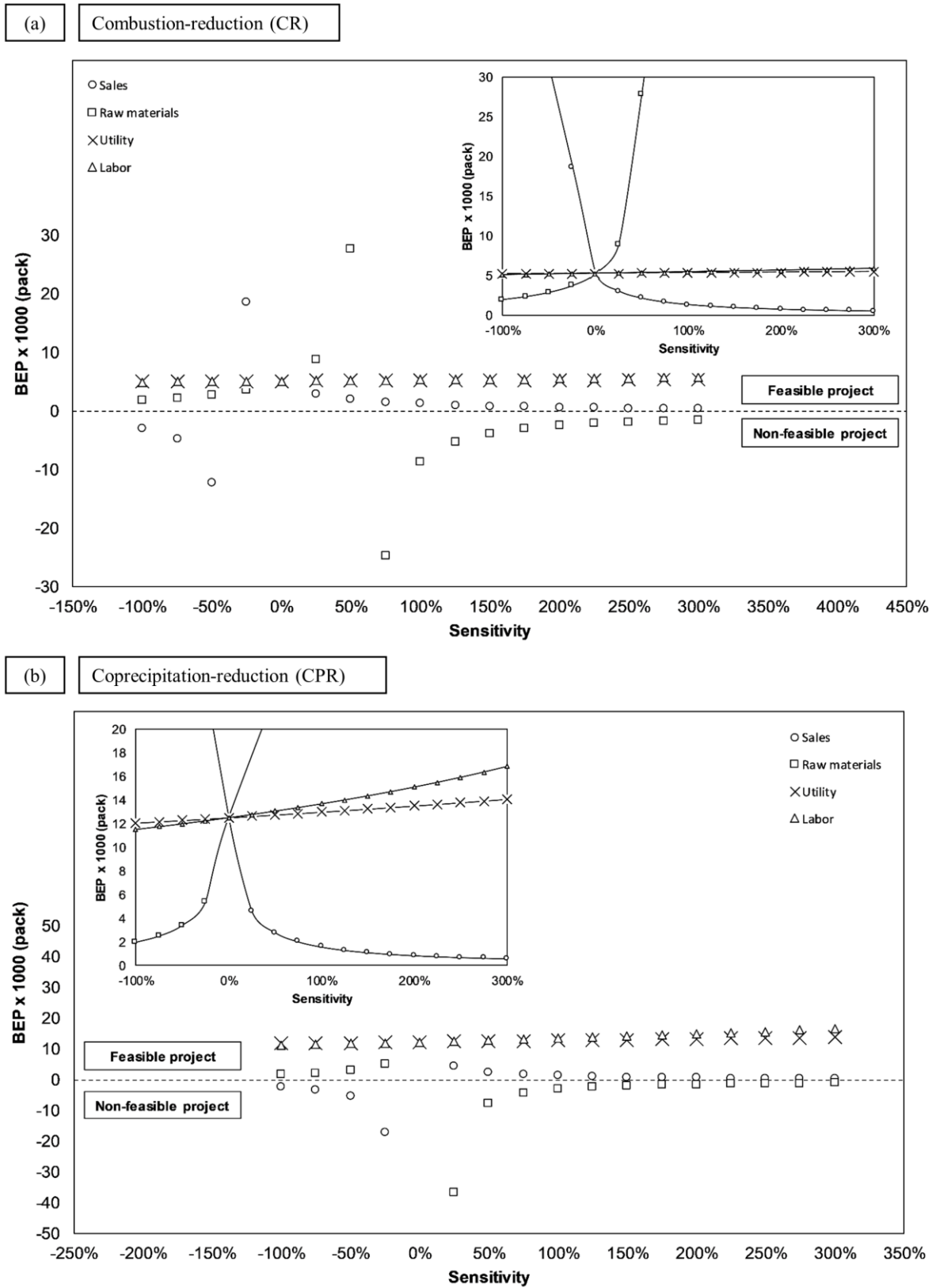


Fig. 8. Analysis of BEP as a function of sales, raw materials, utility, and labor for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR). An insert image is the analysis of BEP in the specific range (-100% to 300%)

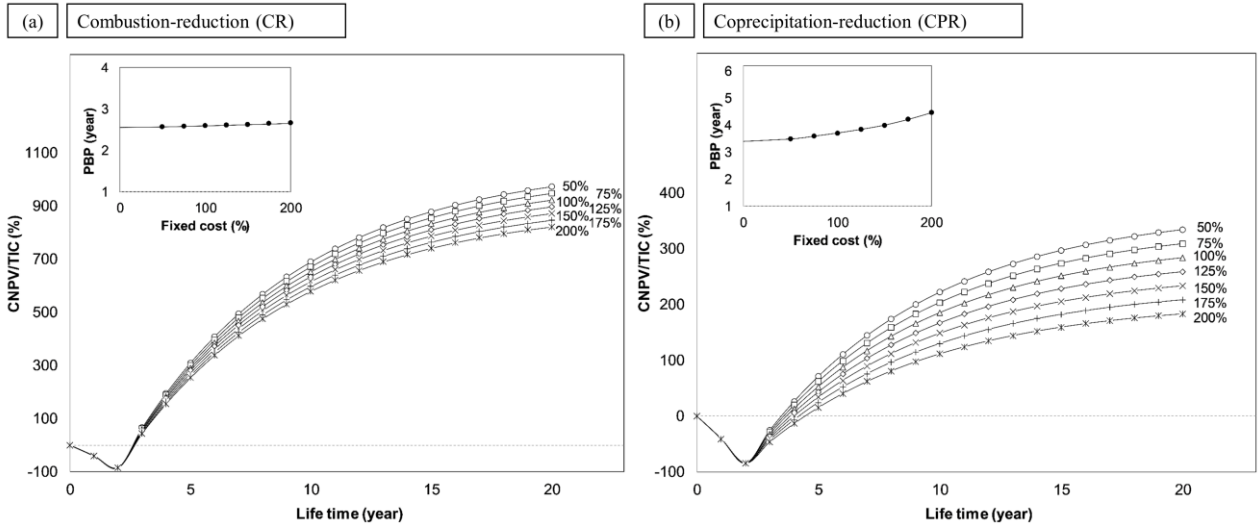


Fig. 9. CNPV/TIC curves in accordance to life time for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR) under various fixed costs. An insert image is the analysis of PBP based on fixed costs.

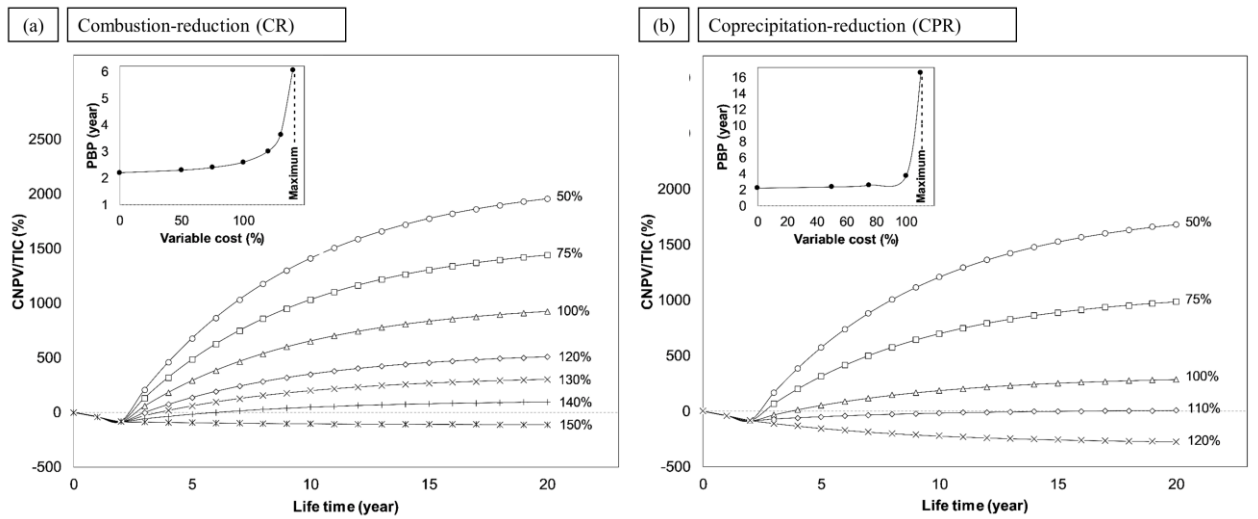


Fig. 10. CNPV/TIC curves in accordance to life time for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR) under various variable costs. An insert image is the analysis of PBP based on variable costs.

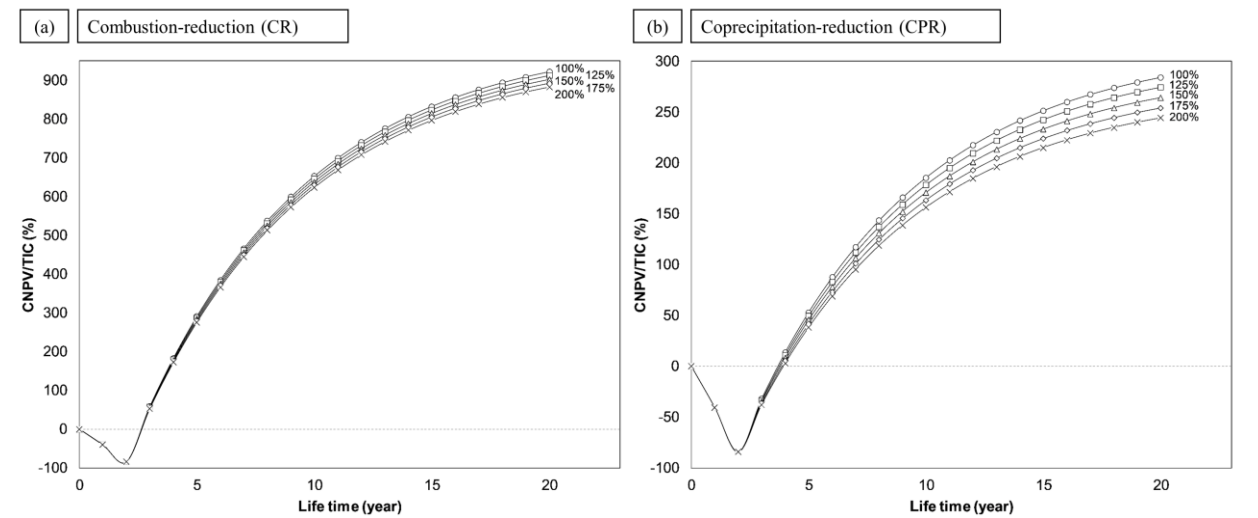


Fig. 11. CNPV/TIC curves in accordance to life time for (a) combustion-reduction (CR) and (b) co-precipitation-reduction (CPR) under various employee numbers

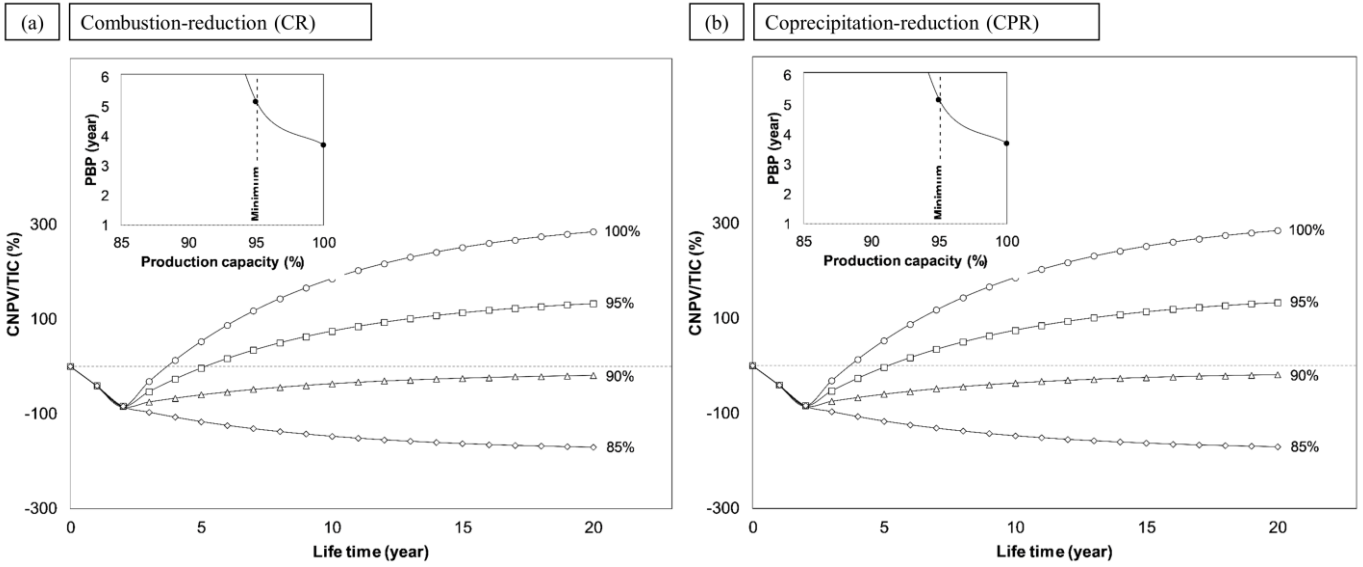


Fig. 12. CNPV/TIC curves in accordance to life time for (a) combustion-reduction (CR) and (b) coprecipitation-reduction (CPR) under various production capacities. An insert image is the analysis of PBP based on production capacities.

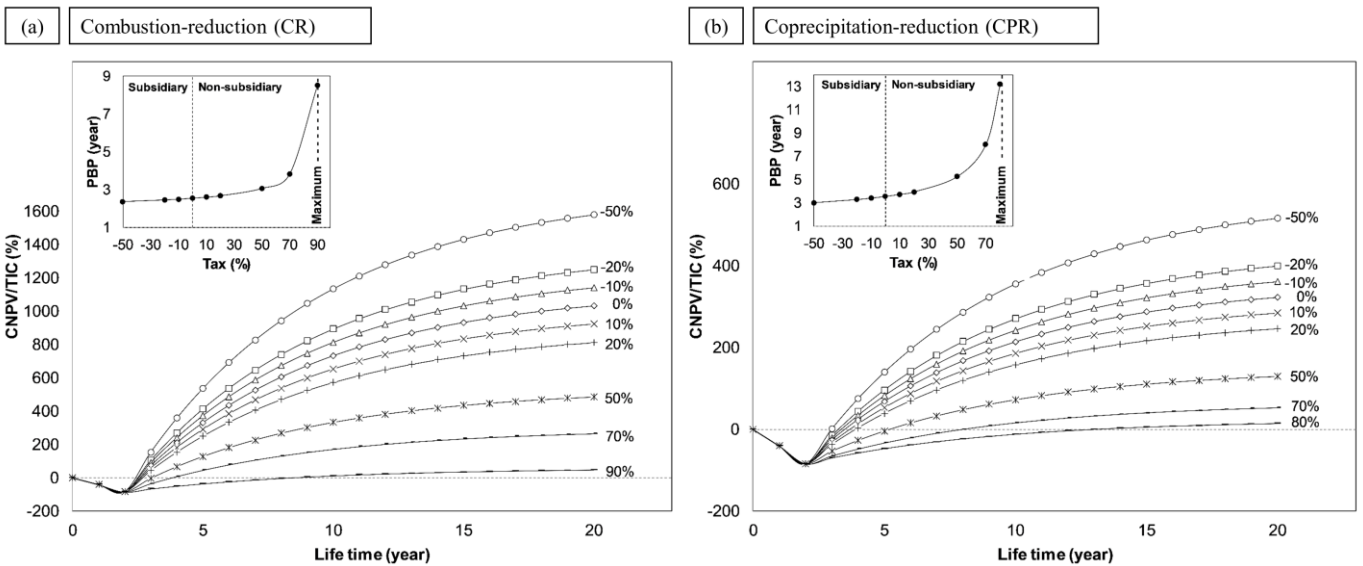


Fig. 13. CNPV/TIC curves in accordance to life time for (a) combustion-reduction (CR) and (b) co-precipitation-reduction (CPR) under various taxes. An insert image is the analysis of PBP based on taxes.

3.7. External Issues: Changing taxes and subsidiaries

Economic condition in a country where the project is conducted is one of the most influencing external parameters[9]. This is a parameter to predict the successful project in which the country could give a tax or a subsidiary from the government itself. Moreover, this condition could be beneficial or detrimental to the project dependent upon their economic policies.

Fig. 13 shows CNPV/TIC curves under various taxes and subsidiaries. The figure confirmed that changing taxes has greatly affected to the value of CNPV/TIC started from the second year. Initial years (from 0 to 2) showed the identical results to the ideal condition, considering that the interval was the initial period of project construction. The effects of taxes on the CNPV/TIC could be obtained after the project was

established in the second year. Indeed, this condition also influenced the PBP. Increases in taxes resulted in less benefit for all methods, slowing down the PBP. In this figure, the maximum tax to get PBP should be less than 90% for CR and 80% for CPR. Changing taxes to more than these values created failure in the project.

The analysis of changing taxes also relates to PBP. The maximum tax will get the payback after 8.49 years for CR and 13.21 years for CPR. As shown in an insert image in Fig. 13, there is a negative tax on x axis. It means that the additional charge was given by the government as a subsidiary cash for the project. Applying additional subsidiary is getting more benefits for the project. When the government gave the subsidiary up to 50% (-50% in graph), the PBP was obtained faster. However, the curves in an insert image describes that the subsidiary was found as it had no significant impact on the

project but increasing taxes to do more influences. Furthermore, CR had a better result than CPR in this external condition case.

Referring to all the results of each internal and external issues, the analysis of feasibility of the project by changing economic circumstances has been conducted and the project of CR scheme has led to a better scheme than CPR. To be carefully noted, both CR and CPR for the production of LaNi_5 materials were profitable only in the specific economic condition. However, if the project works in the circumstances that is out of the specific economic condition, the project is going to suffer much losses.

In addition, all these applications are also still in the research stage. There are many aspects need to be improved and applied in realistic condition. Therefore, the techno-economic analysis could be useful for further developments.

4. Conclusion

This work reported an engineering process design and economic evaluation in the large-scale production of LaNi_5 materials using two types of processing schemes: CR and CPR methods. The projects of both methods were found prospective to be scaled up based on engineering evaluation since the processes can be done using the commercially available apparatuses. The economic analyses from GPM, PBP, BEP, CNPV, and PI showed the positive result, while the one from IRR and ROI showed the negative one, indicating that the project was profitable but less attractive for industrial investors. In the ideal condition and the worst cases, CR method was found better than CPR. Both methods were profitable only in the specific economic condition. This work demonstrated the importance of the projects for supporting the industrial practitioners to further develop.

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6. References

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