Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 12, Page 1966-1975

http://www.jmaterenvironsci.com

Economic Evaluation of Carbon Nanoparticles Production through Non-Thermal Plasma Method

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Received 22 Nov 2020,
Revised 11 Dec 2020,
Accepted 14 Dec 2020

Keywords
- ✓ Carbon Nanoparticles
- ✓ Economic Evaluation
- ✓ Feasibility Study
- ✓ Non-Thermal Plasma Process

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Abstract

Carbon nanoparticles are a material that has superior physical and chemical properties with a wide range of applications. Of the many synthesis methods used, one of the most effective methods of synthesizing carbon nanoparticles is the non-thermal plasma process. This method was chosen because it does not cost much in the process, low energy required and is more environmentally friendly. To determine the feasibility of a carbon nanoparticle production project using a non-thermal plasma process, it requires an evaluation from an economic and technical perspective. The analysis used in this research includes production analysis, Payback Period (PBP), Cumulative Net Present Value (CNPV), project benefits and so on. The results showed that the production of carbon nanoparticles is very prospective. Technical analysis to produce 300 tonnes of carbon nanoparticles per year shows a total cost of equipment to be purchased at 17,041.67 USD, and a total cost for raw materials of 1,003,975.68 USD. This project can compete with PBP capital market standards because the investment returns in a short time which is about 3 years. To ensure project feasibility, projects are estimated from ideal conditions to worst conditions in the production process, including labor, sales, raw materials, utilities, and external conditions such as taxes.

1. Introduction

Currently, carbon nanoparticles are a nanotechnology material that has various benefits from both physical and chemical properties, so many researchers are exploring this study. Carbon nanoparticles are usually used in industry [1], biology, and electronics [2]. In the industrial sector it is used in the production of pharmaceuticals, paper making, textiles, printing, agriculture, steel making, construction and wood processing as coatings, emulsifiers, adhesives, dispersants, and paper additives. One of the applications in the field of bioelectronics is as an electronic element to diagnose a disease.

There are several methods for making carbon nanoparticles, including green synthesis by heating and purification [3], hydrothermal carbonization with the help of organic solvents [4], microwave method [5], carbonization [6], hydrothermal [7], solution plasma process [8], simple heating [9], non-thermal plasma [10], ultrasonic reactions [11], pyrolysis [12], plasma arc discharge [13], microwave irradiation [14] and using atmospheric-pressure and submerged arc plasma reactors [15].

The most appropriate and effective method for economic evaluation analysis is the non-thermal plasma method which has been done by Wang, et al. [10]. The non-thermal plasma method is carried out under adjustable operational conditions and only requires low energy. Another advantage of this method is that it does not cost much to process and is more environmentally friendly. The process scheme for making carbon nanoparticles with a non-thermal plasma method is shown in Figure 1. Microwave method [5], carbonization method [6] and hydrothermal [7] were not selected because requires high temperature. The pyrolysis method of rice husk [12], plasma arc discharge [13], as well as the atmospheric-pressure method and submerged arc plasma reactor [15] require sufficient time long time so that it was not chosen to be the most appropriate method for producing carbon nanoparticles.

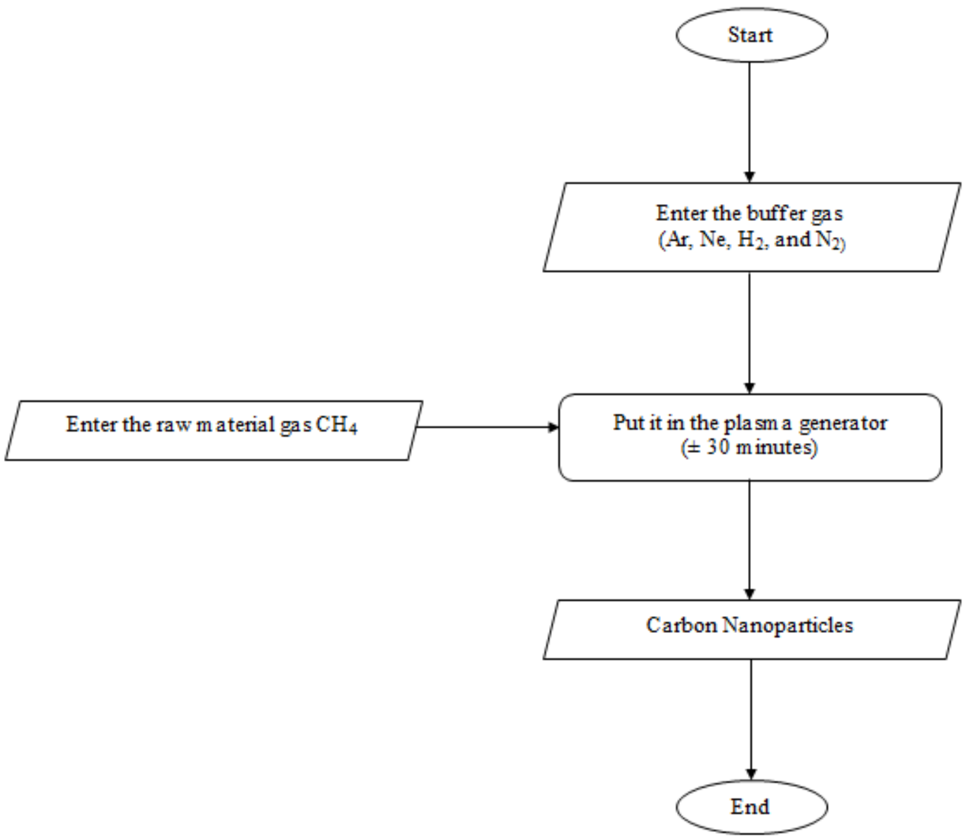

Figure 1: Schematic of the non-thermal plasma method for making carbon nanoparticles

There are a limited number of papers that discuss the economic evaluation of carbon nanoparticle chemical plant designs. Therefore, the aim of this study is to assess the feasibility of non-thermal plasma carbon nanoparticle production activities in terms of economic evaluation. The quantity of raw materials needed needs to be changed from a laboratory scale to a factory scale. Chemical process calculations can be done using a mass balance. This study conducted several economic variations on raw materials, taxes, labor, utilities, and sales.

2. Research Methods

This study uses a method based on economic evaluation that has been designed to include price analysis of materials, equipment and equipment specifications that are commercially available on online shopping sites. All data is calculated based on simple mathematical calculations using the Microsoft Excel application. The following are the economic evaluation parameters:

1) Gross profit margin (GPM) or gross profit is a type of profit that is calculated by subtracting revenue for one period from the cost of goods sold. The gross profit margin calculation is the first step to determine the profitability level of this project.

2) Payback period (PBP) or return on capital is a calculation of the range of time required to refund an investment capital through profit. The payback period is calculated when CNPV reaches zero for the first time.
3) Break even point (BEP) is the point where income is equal to the issued capital, there is no profit or loss. BEP can be calculated by calculating the fixed cost value divided by (total sales price less total variable cost). The BEP calculation can be a projection or estimate of the minimum amount of goods that must be sold during a certain period.
4) Cumulative net present value (CNPV) is a value that predicts the condition of a production project in the form of a production function in years. The CNPV value is obtained from the net present value (NPV) at a certain time. NPV value is the value that states the expenses and income of a business.
5) Profitability index (PI) is a capital budgeting technique for evaluating investment projects for business continuity or profitability. PI can be calculated by dividing CNPV by the total investment cost (TIC). If the PI is less than one, then the project can be classified as an unprofitable project and vice versa.

Several assumptions are based on the process shown in Figure 2. These assumptions show the stoichiometric calculations that produce 1000 kg of carbon nanoparticles. The assumptions:

1) All chemical compositions in the reaction consist of ingredients of high purity.
2) CH_4 reacts with buffer gases such as Ne, He, N_2 and H_2 and each produces carbon nanoparticles of different sizes, and the reacting gas is regenerated.

Several assumptions are used for economic analysis. This assumption is needed to analyze the possibilities that will occur during the process. The assumptions are:

1) All analyzes are in USD currency. 1 USD = 15,000 rupiah.
2) Based on commercially available prices, the prices for CH_4 and buffer gas are 3.42 USD / kg respectively.
3) The total investment cost (TIC) is calculated based on the Lang Factor.
4) It is estimated that one day can produce one cycle of the process of making carbon nanoparticles.
5) Postage costs are borne by the buyer.
6) Carbon nanoparticles sell for 8 USD / kg.
7) One year's project is 300 days (the remaining days are used for cleaning and repairing tools).
8) To simplify utility, the utility unit is described as a unit of electricity such as kWh, then the unit of electricity is assumed to be the cost. Assuming a utility cost of 0.092 USD / kWh.
9) Total wages / labor are assumed to be fixed at 80 USD / day.
10) Discount rate is 15% per annum.
11) The annual income tax rate is 10%.
12) The project operation length is 14 years.

Economic evaluation is conducted for project feasibility test. This economic evaluation is carried out by varying the tax value at 10, 25, 50, 75 and 100%, while the variations in sales, raw materials, labor and utility are carried out at 80, 90, 100,110 and 120%.

3. Results and discussion

3.1 Engineering Perspective

The process of making carbon nanoparticles using the non-thermal plasma method is carried out using several instruments arranged systematically. Buffer gas is fed into the generator for plasma generation.

Then raw material gas is injected continuously into the plasma region. Raw material gases form carbon nanoparticles and other gaseous products rapidly. Carbon nanoparticles are produced in the gas phase. Carbon nanoparticles flow along the gas stream and then settle on the inner walls of the collecting chamber by gravity or adhesion. The gas product and some carbon nanoparticles are emitted into the chamber through the exhaust outlet, so that the pressure during synthesis is ± 1 atm [10]. Figure 2 shows the process of making carbon nanoparticles using the non-thermal plasma method.
The process of making 1000 kg of carbon nanoparticles requires 279 kg of CH_4 gas, 241 kg of Ar gas, 148 kg of He gas, 182 kg of H_2 gas, 128 kg of N_2 gas, and 22 kg of air. In one year, the project can produce as many as 300,000 kg of carbon nanoparticles. The by-products of this project are Ar gas, He gas, H_2 gas, N_2 gas, and O gas. The byproducts are not used.

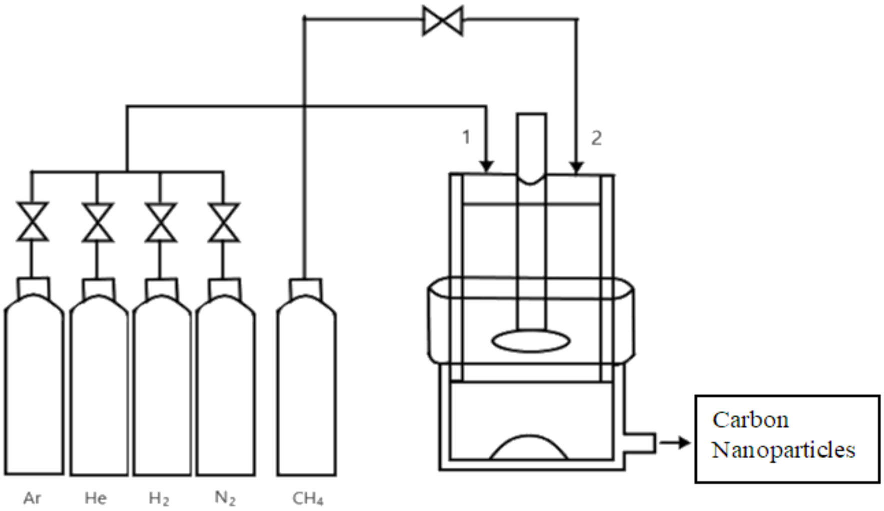

Figure 2: Process flow diagram of carbon nanoparticles

Table 1: Table flow diagram process

No	Symbol	Information
1	Ar	Buffer Gas
2	He	Buffer Gas
3	H_2	Buffer Gas
4	N_2	Buffer Gas
5	CH_4	Raw Material
6	1	Buffer Gas Inflow
7	2	Raw Material Inflow
8	Carbon Nanoparticles	The resulting product

From an engineering point of view, this project produced about 300 tons of carbon nanoparticles by consuming about 83.7 tons of CH_4 gas, 72.3 tons of Ar gas, 44.4 tons of He gas, 54.6 tons of H_2 gas, N_2 gas around 38.4 tonnes, and about 6.6 tonnes of air per year under ideal conditions. The total cost to be paid for raw materials during one year is 1,003,975.68 USD. The total cost to pay for the equipment for one year is 17,041.67 USD. The sales in one year were 2,400,000 USD and the profit earned per year was 1,168,626.13 USD. The Lang factor added to the calculation shows the TIC must be less than 57,941.68 USD. This value is relatively economical, so this project only requires less investment funds. The project life of 13 years produced 3300 tonnes of carbon nanoparticles with CNPV / TIC reaching a value of 70.8 in year 13 and PBP reaching in year 3.

3.2 Economic Evaluation

1) Ideal Conditions

The ideal condition of a project can be determined by analyzing the relationship graph between CNPV / TIC and time. Figure 3 shows a graph of the relationship between CNPV / TIC and time. The y-axis is CNPV / TIC and the x-axis is life time (year). The graph shows that in years 0 to 2 there has been no increase in income, due to initial capital costs such as the tools and materials needed for the carbon nanoparticle production process. In addition, there is land purchase. Based on the graph, in year 3 shows an increase in income, this condition is the Payback Period (PBP). The profit to cover the initial capital increases until the 13th year. Therefore, the production of carbon nanoparticles can be considered as a profitable project, because this project requires a short time to return the investment cost which is about 3 years. The results of the analysis show that this project shows an ideal project to run in industrial production. According to Sudaryanto [16], the results of the PBP analysis reveal the point where the return capital is less than the project plan age, it can be said to be profitable.

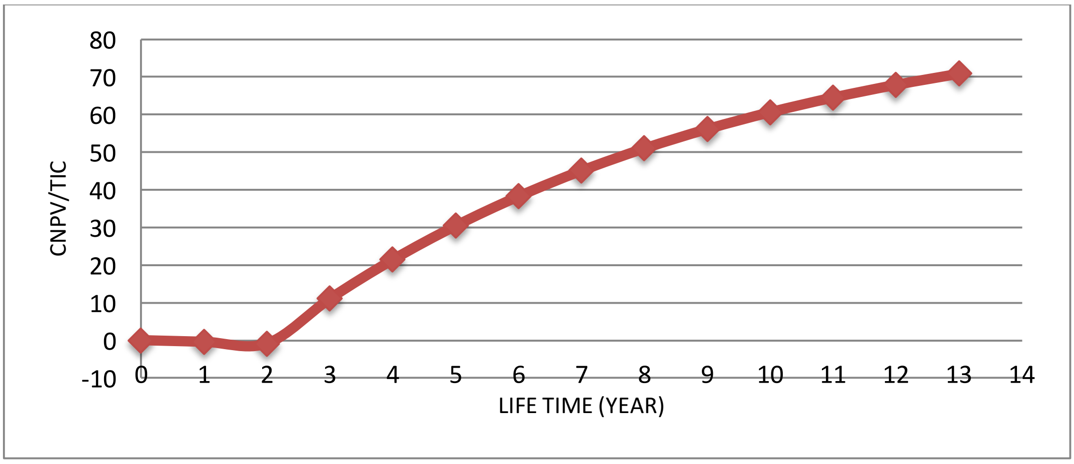

Figure 3: CNPV / TIC ideal conditions for life time (year)

2) The Influence of External Conditions

External factors can affect the success of a project. One of the external factors that most influences the sustainability of a project is the economic condition of the project. This is related to financial costs or other levies imposed on projects by the state to finance various public expenditures. Figure 4 shows a CNPV graph with various tax variations. The y-axis is CNPV/TIC and the x-axis is life time (year). The PBP obtained from various tax variations is shown in Figure 4. In the initial conditions, namely 0 to 2 years, the CNPV project at various tax variations is the same, due to project development. The tax effect on the CNPV project is acquired after more than 2 years. When tax costs are added to the project, the project profits will decrease. Based on the results of the PBP analysis, funds returned when the taxes to be paid were 10, 25, 50, 75, and 100% which were achieved in year 3. Meanwhile, the project loss is when the tax to be paid is 100% of ideal conditions. Profits continue to increase after reaching the Payback Period (PBP) point until the 13th year. However, the distance between the profits generated for each year gets smaller as the tax increases. The CNPV/TIC values in the 13th year for each variation of 10, 25, 50, 75 and 100% were 70.84; 58.92; 39.05; 19.18; and -0.68. Thus, the maximum tax for obtaining BEP (the point at which profit or loss on the project) is 75% The existence of a tax of more than 75% causes failure in the project. According to Nandiyanto, A. B. D [17], the results of the analysis reveal that the more taxes that are added to the project, the less profit is obtained.

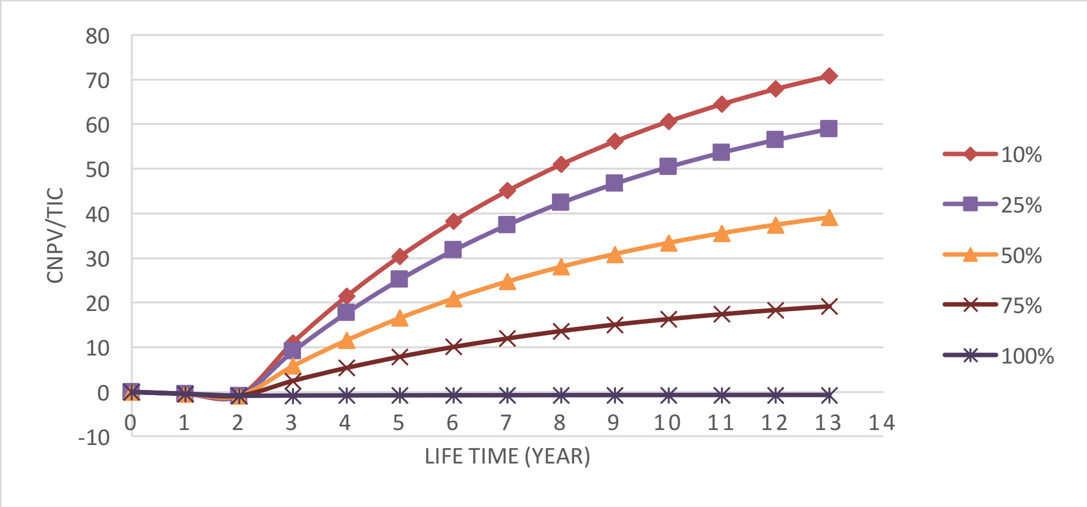

Figure 4: CNPV curve of tax variation on life time (year)

3) Change in Sales

Figure 5 shows the CNPV chart on various sales variations. The y-axis is CNPV/TIC and the x-axis is life time (year). The analysis is done by increasing and decreasing sales by 10 and 20%, with ideal sales of 100%. When sales are decreased by 10 and 20%, sales are 90 and 80%, respectively. When sales are increased by 10 and 20%, sales are 110 and 120%. The PBP results for various sales variations are shown in Figure 5. The initial conditions, namely 0 to 2 years of CNPV project in various sales variations are the same, this is due to project development. The effect of sales on CNPV is obtained after the project has been in development for more than 2 years. The greater the sales value, the higher the profit. However, if the conditions that cause product sales to decline, the project profit will decrease from the ideal state. Based on PBP analysis, funds that return when there are sales variations of 120, 110, 100, 90 and 80% can be achieved in year 3.

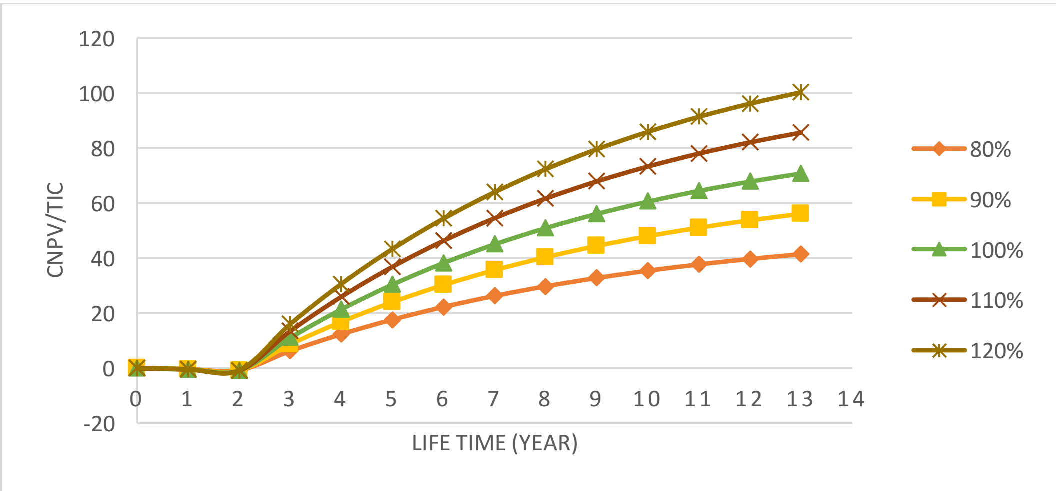

Figure 5: CNPV curve of sales variation against life time (year)

Profits continue to increase after reaching the Payback Period (PBP) point until the 13th year. However, the gap in profits generated for each year gets less and less as sales decrease and losses when sales are 20% of ideal conditions. On the other hand, the profit distance generated for each year increases with increasing sales from ideal conditions. The CNPV/TIC values in the 13th year for each variation of 120, 110, 100, 90 and 80% were 100.35; 85.59; 70.84; 56.09; and 41.33. Thus, the minimum sales to earn BEP (the point at which profit or loss on the project) is 80%. A change in sales of less than 80% results in project failure. According to Nandatamadini *et al.* [18], sales are profitable if they are increased by more than 100%. Since the graph shows a positive CNPV/TIC value, the project is feasible.

4) Changes in Variable Costs (raw materials, labor, utilities)

The success of a project is influenced by internal factors such as the condition of raw materials, labor and utility. Figure 6 shows a CNPV graph on a variety of raw materials. The y-axis is CNPV/TIC and the x-axis is life time (year). The analysis was carried out by decreasing and increasing the raw material by 10 and 20% and the ideal raw material was 100%. When the raw material is reduced by 10 and 20%, the raw material becomes 90 and 80%, respectively. When the raw material is increased by 10 and 20%, the raw material becomes 110 and 120%. PBP is obtained from the variation of raw materials.

In Figure 6, the conditions of the CNPV project from the beginning to 2 years on various variations of raw materials are the same, this is due to project development. The effect of raw material on CNPV is obtained after the project has been built for more than 2 years. The greater the raw material, the less the project benefits from the ideal state. Vice versa, if the raw material is getting smaller, the project profit will increase. Based on the PBP analysis, funds return when variations in raw materials of 80, 90, 100, 110 and 120% are reached in the 3rd year respectively. Profits continue to increase after reaching the Payback Period (PBP) point until the 13th year. The distance between the profits obtained every year is getting smaller with the increase in raw materials from ideal conditions. On the other hand, the distance between the profits earned every year increases with decreasing raw materials from ideal conditions. The CNPV/TIC values in the 13th year for each variation of 80, 90, 100, 110 and 120% were 58.5; 64.7; 70.8; 77; 83.2%. Based on the variation of raw materials, the project can still run and make a profit.

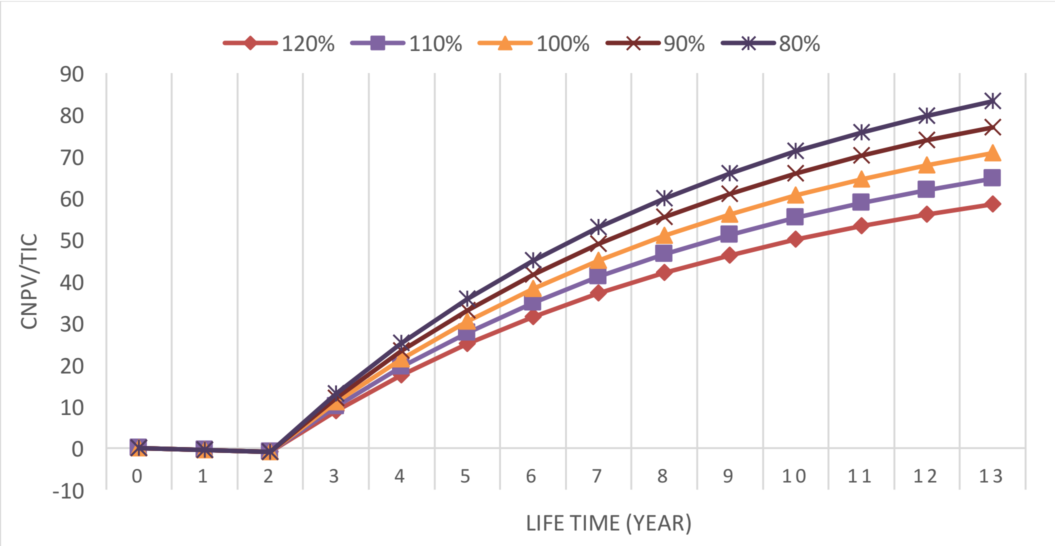

Figure 6: CNPV curve of variation of raw materials on life time (year)

The project of CNPV on various labor variations is shown in Figure 7. The y-axis is CNPV/TIC and the x-axis is life time (year). The analysis was carried out with the ideal salary for workers being 100%, and increasing and decreasing the worker's salary by 10 and 20%. When workers' salaries are reduced by 10 and 20%, the salaries of workers are 90 and 80%, respectively. When the worker's salary is increased by 10 and 20%, the worker's salary will be 110 and 120%. The PBP obtained from the variation of labor salaries is shown in Figure 7. The initial conditions, namely the 0 to 2 year project from CNPV with various variations in labor salaries, are the same, this is due to project development. The labor effect of CNPV is obtained after the project is made more than 2 years. There was no significant change based on the labor variation curve on CNPV. PBP for all variations of the workforce is reached in year 3. The

CNPV/TIC value in the 13th year for each variation experienced a difference, the values were 80, 90, 100, 110 and 120% respectively, 70.3; 70.6; 70.8; 71.1; 71.1%. Based on the variation of the workforce, the project can still run and make a profit.

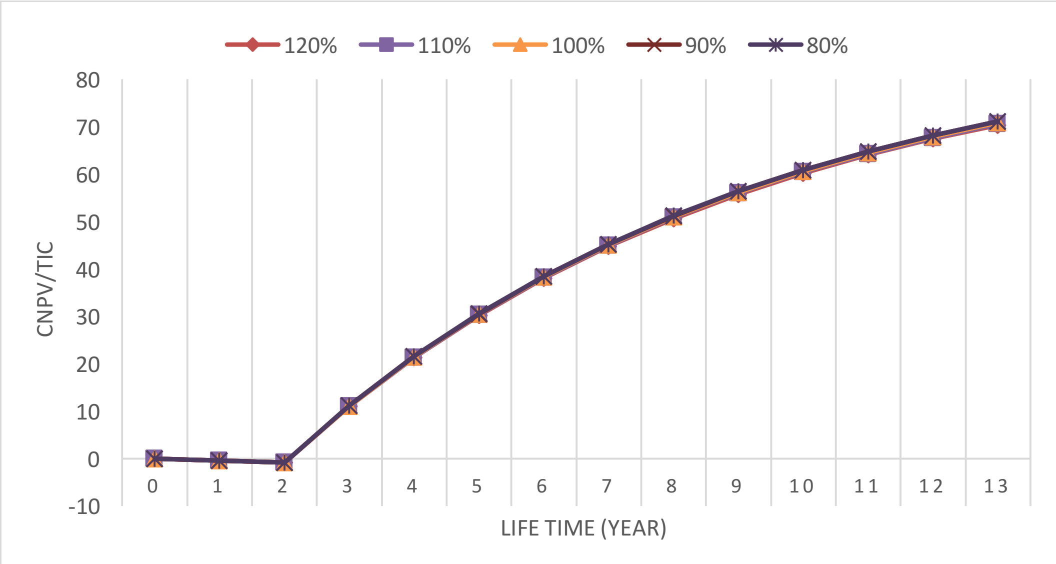

Figure 7: CNPV curve of labor variation to life time (year)

CNPV at various utility variations is shown in Figure 8. The y-axis is CNPV/TIC and the x-axis is life time (year). The analysis was performed with the ideal utility cost of 100%, and the increase and decrease of utility prices by 10 and 20% were carried out. When utility is reduced by 10 and 20%, the utility is 90 and 80%, respectively. When the utility is increased by 10 and 20%, the utility is 110 and 120%. The PBP obtained from the results of the variation in utility is shown in Figure 7. In the initial conditions, namely 0 to 2 years the project from CNPV at various utility variations is the same, this is due to project development. The utility effect on CNPV can be obtained after the project is created from 2 years. There was no significant change in the utility variation on the effect of CNPV. The CNPV/TIC value in the 13th year in each variation experienced a difference, the values were 80, 90, 100, 110 and 120% respectively 70.7; 70.8; 70.8; 70.9; 70.9%. Meanwhile, PBP for each variation of utility is still achieved in the 3rd year. Based on the variation of utility, the project can still run and get profit.

Based on the above analysis, this project is ideal to run in industrial production. This project has the advantage of increasing the initial capital up to the 13th year and requires a short period of time to recover investment costs since PBP which is about 3 years. Carbon nanoparticle manufacturing projects can be profitable under certain economic conditions, despite changes in economic circumstances.

The following is an explanation of the specific conditions: (1) The maximum tax for obtaining BEP (the point at which profit or loss on the project) is 75%. Tax changes of more than 75% will result in failure of the project. (2) Sales must be maintained in a range higher than 80%. When sales are less than 80%, the project will fail. (3) Changes in the price of raw materials with variations of 80, 90, 100, 110, and 120% have an impact on the profits earned each year. The project can still run, but the profit decreases when the raw material price is more than 100%. (4) Labor costs with variations of 80, 90, 100, 110, and 120% have no effect on profits. (5) Utilities or electricity costs with variations of 80, 90, 100, 110, and 120% have no effect on profits. (6) Analysis of variable cost variations plays an important role in determining profit. Increasing the variable cost, the project will experience a decrease in profits. Vice versa, when the value of the variable cost is lower, the project is more effective and generates more profit.

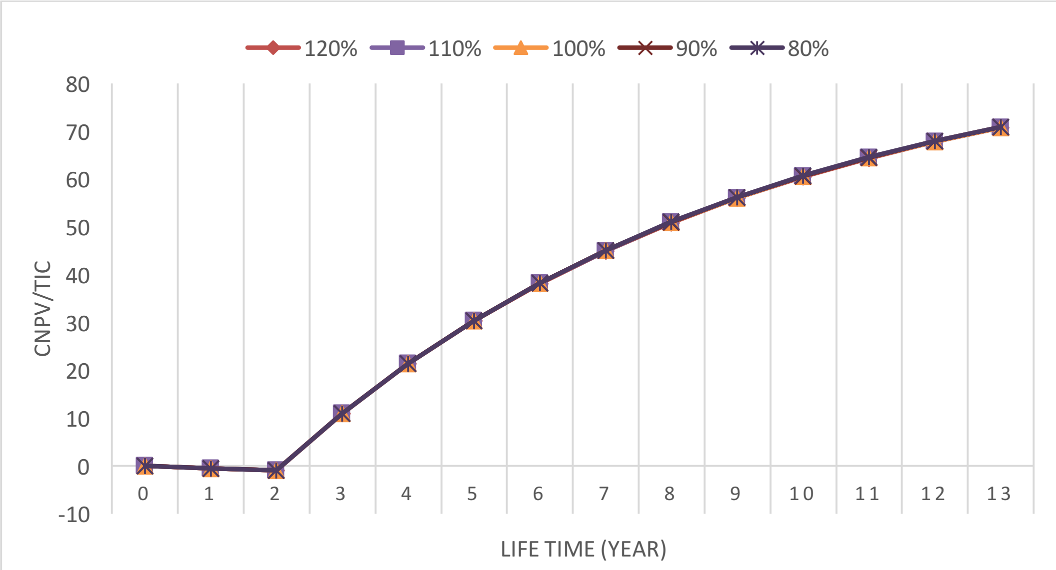

Figure 8: CNPV curve of utility variation on life time (year)

Based on the results of the variable cost analysis, the cost of raw materials has the most important effect, it can be seen in Figure 6, namely the CNPV graph on various variations of raw materials. Apart from economic prospects, analysis of attractiveness needs to be done. This project is likely to be attractive to industrial investors, as it refers to the final CNPV value which is quite high for a project of 13 years, as well as a relatively high PI value. So, for long-term investment this project is attractive to investors. This research provides information and knowledge about the feasibility of producing carbon nanoparticles using the non-thermal plasma method.

Conclusion

The production of carbon nanoparticles using the non-thermal plasma method is considered effective, because it does not cost much in the process, and the energy required is low and is more environmentally friendly. By conducting a production analysis, the carbon nanoparticle production project using the non-thermal plasma method shows a project that is prospective from an engineering point of view. And, it is quite promising from the economic evaluation analysis. This project can compete with PBP capital market standards because the investment returns in a short time which is about 3 years. Based on the economic evaluation analysis, it can be concluded that this project is feasible to run.

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