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An Economic Evaluation on Scalling-up Production of Nano Gold from Laboratory to Industrial Scale

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ABSTRACT

Gold nanoparticles are applicable in various engineering fields such as in biosensors, drug delivery, and tumour imaging. The objective of this study was to evaluate the scaling-up production of gold nanoparticles from laboratory to industrial scale. The evaluation was done from engineering and economic perspectives, in which several parameters including gross profit margin (GPM), and payback period (PBP) were analyzed. From the engineering evaluation, the result showed that the production of nano gold is prospective using current technologies. To produce nano gold, we could use chloroauric acid, sodium citrate, and sodium borohydride, in which these materials can be converted into gold nanoparticles. From the economic evaluation, the result showed that Nano gold production in industry scale can be profitable with a certain condition of raw material. It was shown that the breakeven point, payback period and gross profit margin could be achieved in 20 years.

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1. INTRODUCTION

Gold is a group of noble metals. Now, gold is not only used as electronic information, sensors, information storage and catalysts (Wang & Chio, 1998), but also it is easily made in various other shapes and sizes (Yap & Mohamed, 2008). Nanoparticles material has physical and chemical properties that differ greatly from other materials, such as its catalytic, optical, and thermal stability (Kumar et al., 2013). Because of this, gold nanoparticles have been used in cosmetic products, cancer therapy, and carrier protein (Agasti et al., 2009).

Figure 1 shows a schematic diagram of the synthesis gold nanoparticles by mixing $HAuCl_4$ (*Chloroauric acid*) with *Sodium Citrate* and *Borohydride Sodium* under dilute solution (Verma et al., 2014). The process of synthesizing nanoparticles especially gold nanoparticles could be done through several steps. In a tank containing water, $HAuCl_4$

(*Chloroauric acid*) is mixed with *Sodium Citrate* with a mol ratio of 1: 1. The mixture is added with *sodium Borohydride*. The optimum reaction at a temperature of 150°C and with stirring speed of 280 rpm for 1 hour. This condition has been studied to have better stability, which is 2 months. Changing the color of the product to burgundy indicates gold nanoparticles have been formed. Then the solution is cooled. *Sodium Citrate* and *Sodium Borohydride* are stabilizer agents in the formation of nanoparticles in either gold or other nanoparticles. Because nanoparticles are substances that are quite susceptible both in conditions of temperature, pH and other conditions, so that a substance that can stabilize these nanoparticles is needed to prevent agglomeration of nanoparticles resulting in nanoparticles joining to form larger formations. This compound is often used only by one or a combination of the two. In the next step, the mixture was evaporated to obtain gold nanoparticles with a concentration of 0.01%. Then the solution is filtered with a pore membrane that is quite small, so that the gold reagent that does not change into nanoparticles can be separated from the solution. This is quite important because when there are larger particles, smaller particles (nanoparticles) will tend to form agglomerates with these large particles.

Research and development on gold nanoparticles (AuNPs) has greatly increased. Nanoparticles are very small particles with a diameter between 1-100 nm. Nanoparticles can be found in various forms such as balls, cubic, pentagonal, and beams (Yu & Yam, 2005). The nature of most important nanoparticles is that they have different colors depending on the diameter (Widyanti, 2010). It was found that material containing nanoparticles has properties that are different from properties in bulk sizes (Cao, 2010). These differences occur in the physical, chemical and biological properties (Yanti & Taufikurohmah, 2013). Nanoparticles can also be visible because they are small enough to scatter light and to absorb them. For example, gold nanoparticles appear dark red in solution. In addition, the general properties of nanoparticles that apply to various tissues and organs in the body are easily faced with various biological barriers (Martien et al., 2012).

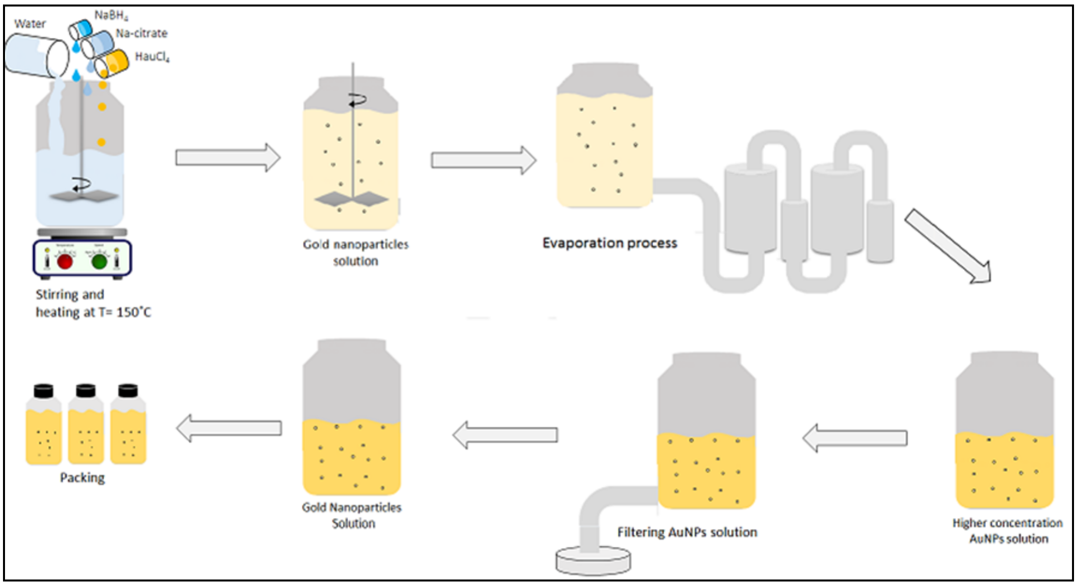

Figure 1. Scheme of the Synthesis Gold Nanoparticles

The synthesis and characterization of gold nanoparticles has attracted many attentions from fundamental to practical application. Schmid (2010) and Fedlheim & Foss (2001) reported that various synthesis has been generated to regulate gold nanoparticles production. Moreover, the synthesis of AuNPs can be done by chemically (bottom up) in which it is done by reducing gold in the form of salt, and also it can be done physically (top down) in the form of bulk (Kumar & Yadav, 2009). Brust et al. (1998) provided study on gold nanoparticle with nonmetallic optical and electronic properties. However, lack of studies could be found related to the economical aspect of scale-up production of Nano Gold Production from laboratory to industrial application.

To evaluate the scale-up production of gold nanoparticles (AuNPs) from laboratory to industrial scale, the present study adopted a synthesis method from Li et al. (2014). In the present work, two perspectives of studies, engineering and economic evaluation were done. To support the economic evaluation, some economical parameters were analyzed and discussed.

2. RESEARCH METHODOLOGY

The data used in this study for gold nanoparticles synthesis is the secondary data taken from existing reports of (Brust et al., 1994), (Brust et al., 1995), and (Sun & Xia, 2002). The data were scaled up with a larger number to be applied on an industrial scale application. As for the price data, it was obtained from several online shops available. Several economic parameters were then used in the analyses which are as follows:

1. GPM (gross profit margin) to predict the rough analysis of the economic condition),
2. BEP (break-even point) to get the minimum requirement of the production capacity),
3. PBP (payback period) to estimate the possibility for the year of profit),
4. CNPV (cumulative net present value) to predict the condition of the project as a function of year of production).

Calculation of mass balance and economic parameters can be obtained by the following assumptions:

1. Solid $HAuCl_4$ has high purity,
2. Solid Sodium Citrate has high purity,
3. Solid *Borohydride Sodium* has high purity,
4. The water used has minimal contaminants,
5. The filtration process runs well,
6. The mole ratio of $HAuCl_4$ with *Sodium Citrate* is 1: 1,
7. Stoichiometry obtained 0,000126% of dissolved gold nanoparticles. However, it is considered 0,0001%, considering the efficiency of the reaction,
8. 1 USD is equivalent to 10,000 IDR,
9. Synthesis is done 20 times per day,
10. Salaries are given 24,000 USD per year for 8 workers,
11. Incoming Tax 10%,
12. Price of 100 mL gold nanoparticle solution = 450 USD,
13. Production runs for 20 years.

The calculation was done by changing sensitivity of sales and raw material cost. Then, the PBP is acquired from the CNPV curve.

3. RESULT AND DISCUSION

Table 1 shows various GPM in raw materials and product for various sensitivity. **Figure 2** shows the effect of the price for each raw material (from -100% to 100%) and the product to the gross profit margin

(GPM). It is known that product prices will obviously have a major impact on the industry's GPM. However, changes in prices in raw material did not have a significant impact on the GPM obtained. This is due to product prices increasing many times compared to material prices.

As can been seen in **Figure 3** that that *chloroauric acid* acting as the main raw material had a significant effect on GPM followed by *Sodium borohydrate* and *sodium citrate*. This is quite easy to predict, because sodium citrate has a fairly low price compared to the other two raw materials.

Table 1. Various GPM in Raw Materials and Product for Various Sensitivity

Sensitivity	GPM (USD)			
	Chloroauric Acid	Sodium Citrate	Sodium Borohidrate	AuNPs
100%	13010374,06	12657373,08	12789574,92	-14342677,94
50%	12922111,06	12657360,33	12756511,7	-7592677,937
0%	12833848,06	12657347,57	12723448,49	-842677,9365
-50%	12745585,06	12657334,82	12690385,28	5907322,064
-100%	12657322,06	12657322,06	12657322,06	12657322,06

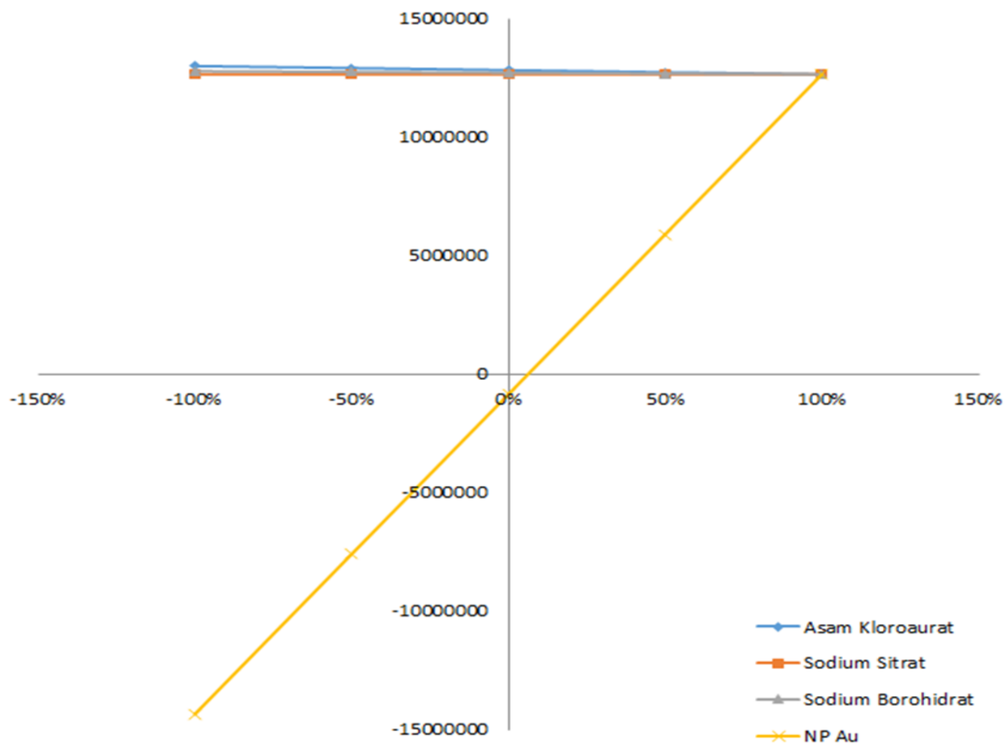

Figure 2. Graph Relation Between Various Price of Raw Material and Product with GPM

Figure 4 shows the condition of CNPV from year to year. From the graph, it can be seen that the production of gold nanoparticles is promising. With investments that are quite low in the initial year, profits can already be obtained in the third year to cover the initial capital that has been spent. This condition is referred to as the Payback Period (PBP), assuming that production runs 100% without constraints. From the data analysis, it was also found that by producing 10 products per day, the conditions of the industry did not experience gains or losses. This condition is called Break Even Point (BEP).

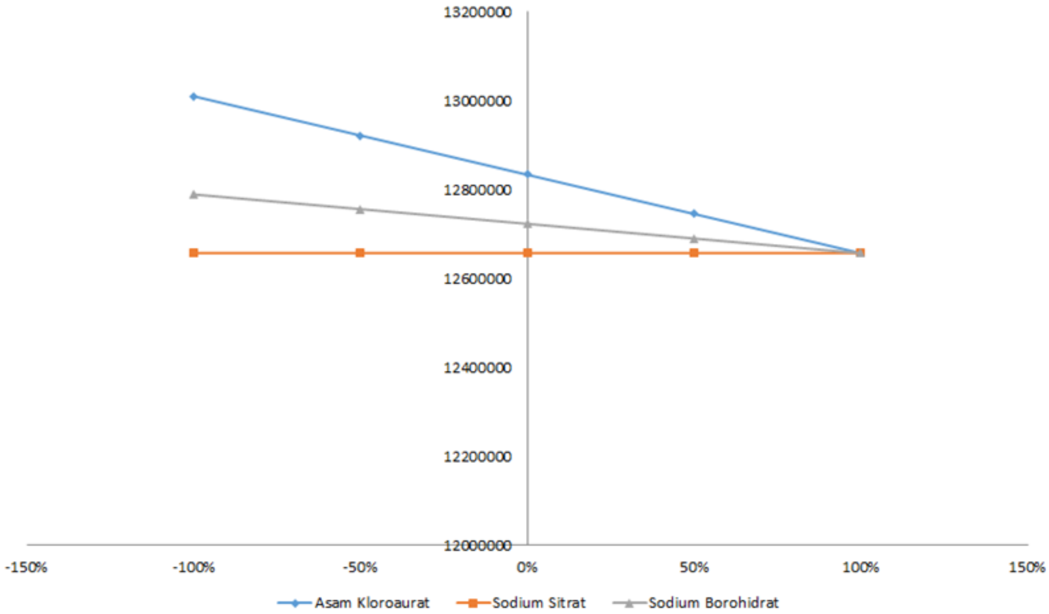

Figure 3. Graph Relation Between Various Price of Raw Material with GPM

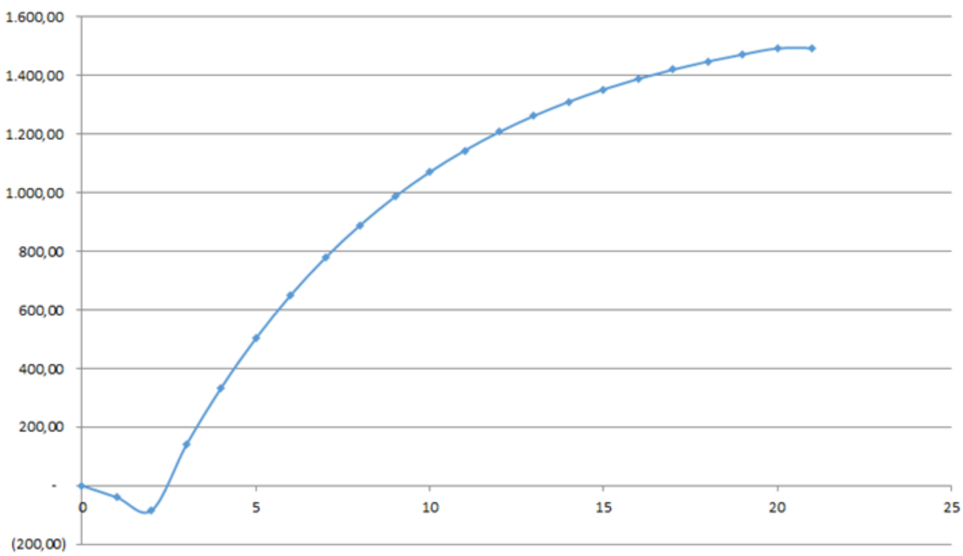

Figure 4. Graph CNPV/Investment as Long as Twenty Years

In **Figure 5**, it is shown, although the variable cost is varied (100%, 50%, 0%, -50%, and -100%), the production of gold nanoparticles remains quite profitable. With BEP and PBP which remain at the initial number. This shows that the production of gold nanoparticles has quite high stability in fairly volatile market conditions.

In **Figure 6**, it is shown, although the variable tax is varied, the production of gold nanoparticles remains quite profitable. Only the very high tax the production of gold nanoparticles unprofitable. And **Figure 7** shows that production still profitable with various production capacities.

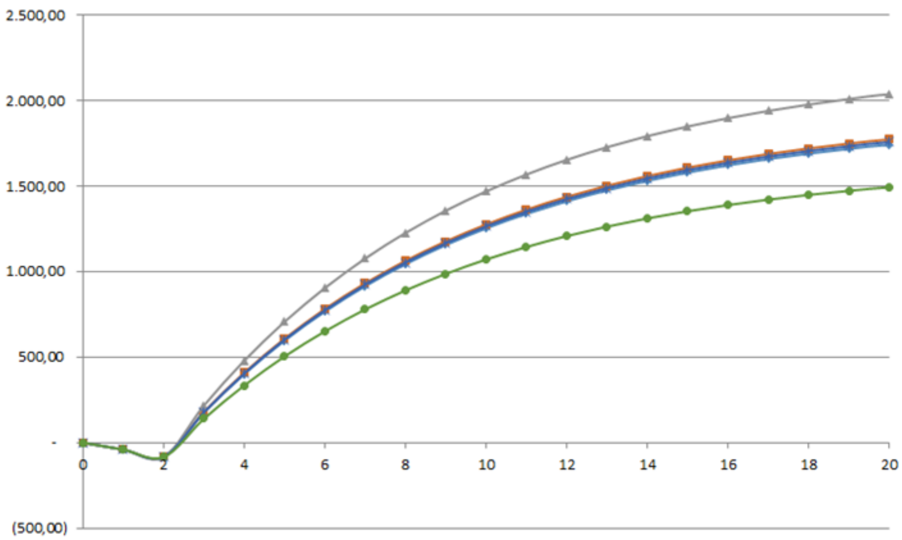

Figure 5. Graph CNPV/Investment as Long as Twenty Years with Various Variable Cost

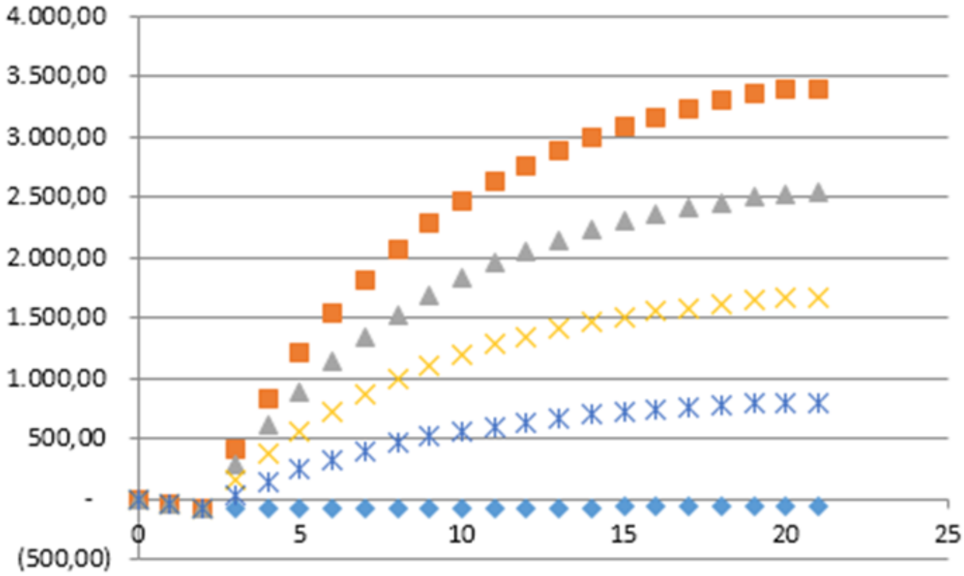

Figure 6. Graph CNPV/Investment as Long as Twenty Years with Various Variable Tax

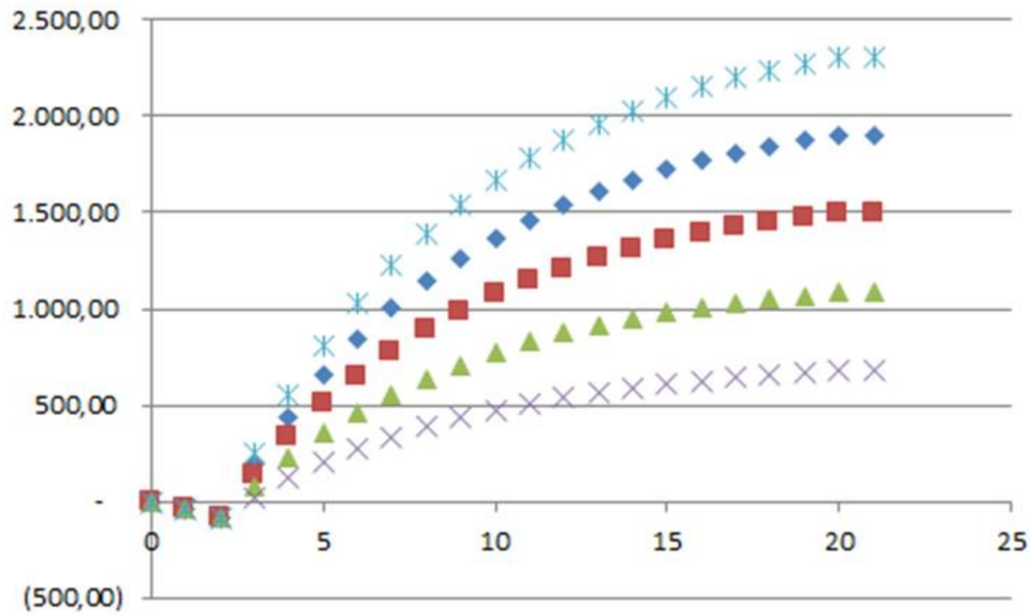

Figure 7. Graph CNPV/Investment as Long as Twenty Years with Various Variable Production capacities

4. CONCLUSION

In this study, the production of gold nanoparticles on an industrial scale was quite beneficial when viewed from several factors: CNPV / investment for 20 years, BEP which was quite low with only 10 production / day, fast BPB of 3 years, GPM which was relatively stable with changes in raw material conditions. Although it has a large initial capital and further research is needed to improve reaction efficiency. This study shows that the industry will become a promising project in the future.

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