Optimization of Corn Stover Gasification Used for Electricity and Hydrogen Production in East Lampung Regency, Indonesia

M Aldi Nugroho[1], Yohanes Maruli Arga Septianus[2], Salsabila Aminatun Muthmainnah[3], Mutia H Br Sinuraya[4], and Dian Kusumawati[5], Vincentius Glorio Fransduard Gospely Goldant[6]
Sepuluh Nopember Institute of Technology
**Corresponding author. Email:* aldinugroho637@gmail.com

ABSTRACT
Rapid industrial development and population growth increased the energy demand. However, electricity production produces emissions and is non-renewable, so energy development is executed to fulfill the energy needs and overcome climate change. Biomass from corn stover waste in East Lampung Regency, Indonesia, has excellent potential as energy with an abundant source, up to 623.93 tons in 2015, and has yet to maximize utilized. This research aims to produce electricity and hydrogen while reducing CO_2 emissions by utilizing corn stover waste using gasification. This research was conducted by simulating using Aspen Hysys to determine the technology's operating conditions, efficiency, and feasibility. As a result, the mechanism is that corn stover biomass is put into a gasifier for drying at 150°C. Then, pyrolyzing at 500°C to separate the volatile materials from the charcoal while adding a CaO catalyst. Furthermore, CO_2 and H_2O are produced, which will be reduced by the gasifier and produce fuel gases to drive an electric generator and separated in a hydrogen tank. It shows effectiveness by 49.219%, can reduce 119,803.6 tCO_2 emissions in 10 years, and turn it into electricity of 15,550.831 kWh and 34,363.69 liters of hydrogen.
Keywords: *Corn Stover, Electricity, Gasification, Hydrogen*

INTRODUCTION

Rapid industrial development and population growth have also increased the need for electrical energy. Fossil fuels, the primary energy source, is decreasing so other energy sources are needed to replace the use of fossil fuels. Thus, the impact of climate change caused by fossil fuels has been increasing, considering that fossil fuels contribute almost 78% to greenhouse gases (Lund et al., 2022). Carbon dioxide (CO_2) gas is one of the highest concentrations of greenhouse gases, which can affect the increase in the earth's temperature (Kim et al., 2018). If fossil fuels are still used, it is predicted that there will be an increase in CO_2 emissions reaching 351.3 million in 2028 (Arinaldo et al. 2019). To prevent these problems, the Indonesian Ministry of National Development Planning is committed to reducing CO_2 emissions by 26%. This is a big challenge in reducing greenhouse gas emissions and fulfilling the energy needs which is also part of SDGs targets points 7 and 13 (Boer et al. 2018).

One of the steps that can be taken to answer this challenge is the utilization of bio energy. Biomass energy has many characteristics similar to fossil energy but is more renewable and sustainable (Ellabban et al. 2014). Bioenergy production is generally related to using natural raw materials, starting from the main ingredients to the waste. Corn stover waste in East Lampung Regency has a promising potential to be used as an environmentally friendly energy source because of its abundant amount. Data from the Central Bureau of Statistics for Lampung Province in 2015 showed that corn stover waste reached 623.93 tons per year (Slameto, 2021). Corn stover waste has great potential to be used as biomass considering its composition is lignocellulosic, which contains 39-47% cellulose, 27-32% hemicellulose, and 3-5% lignin (Tari, 2020).

An appropriate processing method is needed to convert corn stover waste into biomass so that the energy produced will be significantly valued. So far, the most widely used biomass processing method is the gasification method because this method is proven to be able to produce large amounts of electricity in a short time so that production costs can be reduced (Siswati, 2012). Sodium carbonate catalyst was used for wood gasification to speed up the reaction process in the gasification reactor. However, the catalyst experienced a decrease in its reactivity before gasification was completed (Nzihou et al., 2019). Then, adding calcium oxide to the carbon dioxide gas absorption process reduced CO_2 levels significantly because calcium oxide reacted with carbon dioxide and formed calcium carbonate products (Florin et al., 2011). On the other hand, the gasification process still produces CO_2 emissions, and the resulting hydrogen (H_2) gas is still limited due to thermodynamic equilibrium (Li et al., 2017).

In response to the deficiencies mentioned above, the authors propose corn stover waste gasification to produce electricity and hydrogen while reducing CO_2 emissions by utilizing corn stover waste using the gasification method. The gasification process is carried out by adding calcium oxide to reduce CO_2 produced from the gasification process while increasing the concentration of hydrogen produced. This research was conducted by simulating the gasification process using ASPEN PLUS V11 to determine the operating conditions, efficiency, and feasibility of corn stover waste gasification technology for the corn stover waste gasification process.

MATERIAL AND METHODS

The research method used by researchers is research and development method to carry out research starting from literature studies to obtain information related to problems and potential, obtain information regarding the gasification process and the content of corn stover waste, and develop the corn stover waste gasification process by looking at technological and economic aspects. The simulation method with ASPEN PLUS V11 was carried out to determine the maximum operating conditions and the mechanism of the gasification process to produce electricity and hydrogen energy. The flow of research conducted can be seen in Figure 1.

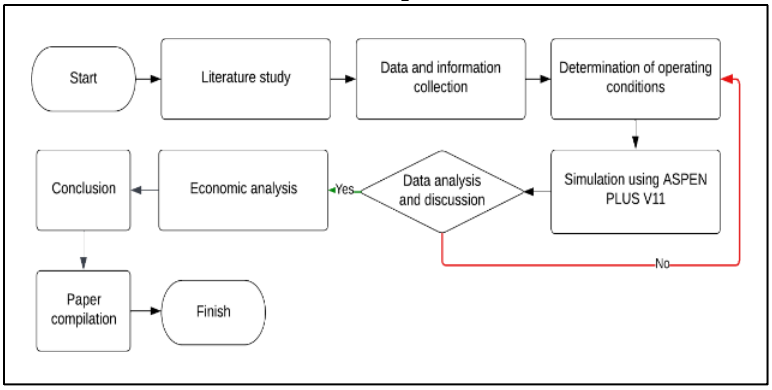

Figure 1 Research Flowchart

a. Equipment and Materials

As for the equipment that has been used to simulate the gasification process of corn stover waste with the addition of calcium oxide catalyst in ASPEN PLUS V11, gasifier, power storage, turbine, gas separator, and hydrogen storage, as for the materials used are corn stover waste as biomass and calcium oxide catalyst.

b. Operating Conditions

The operating conditions used in the gasification process are to utilize corn stover waste to produce electricity and hydrogen products, the drying process at 150°C. Then the process of pyrolysis, gasification, and oxidation at a temperature of 500°C (Mahmoudi, 2015). The following description of the gasification process used is shown in Figure 2.

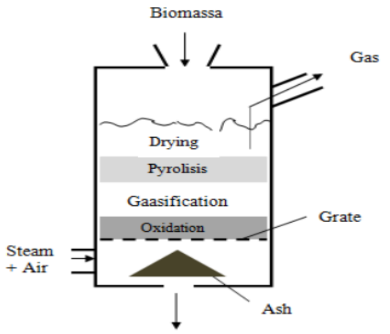

Figure 2. Schematic of the Gasification Process

c. Calculation

The effectiveness of electricity and hydrogen production using corn stover waste gasification technology can be determined by calculating the fuel consumption rate, the mass of gas from the gasification process, calorific value of gasification, gasification efficiency, amount of hydrogen and electricity produced, and CO_2 Emission Reduction Potential.

a) Fuel Consumption Rate

The fuel consumption rate shows how much fuel is needed for the combustion process in the corn stover waste gasification technology (Al-afifi et al., 2021). The calculation of the value of the fuel consumption rate is as follows:

$$\textit{Fuel Consumption Rate} = \frac{mass}{time} \quad (1)$$

b) Mass of Gas from the Gasification Process

The gas mass from the gasification process is the result of multiplying the density of the corn stover waste mixture by the total mass of the waste (Al-afifi et al., 2021). The calculations are as follows:

$$MSyngas = \rho \; x \; mass \; of \; corn \; stover \quad (2)$$

c) Caloric Value of Gasification

Calculating the caloric value of the gasification process is carried out by multiplying the gas mass from the gasification process with the total calorific value of 1 ton of syngas (LHV). The calorific value of the gasification process:

$$Q = (MSyngascornstover \; x \; LHV) \quad (3)$$

d) Gasification Efficiency

The efficiency of the gasification process is determined based on the levels of Lower Heating Value (LHV) and Highest Heating Value (HHV) in the biomass used. The gasification efficiency value of the gasification process:

$$\eta = \frac{MSyngas\ x\ LHV}{MBiomassa\ x\ HHV} x100\% \quad (4)$$

e) Electricity and Hydrogen

The calculation of the amount of electricity generated using corn stover waste gasification technology is as follows:

$$Electricity = \frac{Caloric\ value\ of\ gasification}{360} \quad (5)$$

Calculation of the amount of hydrogen produced using corn stover waste gasification technology:

$$H_2 = (Syngas\ x\ gasification\ efficiency)/10 \quad (6)$$

f) CO_2 Emission Reduction (ER) Potential

The potential for reducing CO_2 emissions due to the utilization of corn stover waste into electricity using corn stover waste gasification technology can be calculated by multiplying the generated electrical energy by the biomass emission factor (ef) of 0.0008 and the fuel energy content per kWh as follows:

$$ER = Energy\ x\ ef\ x\ energy\ content \quad (7)$$

RESULT AND DISCUSSION

A. Working Mechanism of Corn Stover Waste Gasification Process

This system uses a gasifier, power storage, turbine, gas separator, and hydrogen storage in the production process. Meanwhile, the raw materials used are corn stover waste and wood as a source of gasifier fuel. As for the design of the corn stover waste gasification technology can be seen in Figure 3.

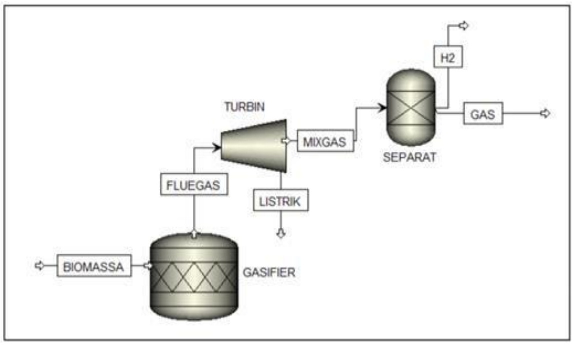

Figure 3. Corn Stover Waste Gasification Design Plant

The working mechanism of corn stover waste gasification technology is that the corn stover biomass is put into the gasifier to be dried at a temperature of 150°C. Then, a pyrolysis process is carried out at 550°C to oxidized through an exothermic reaction and CO_2 and H_2O are produced, which then will be reduced by a gasifier that will produce fuel gas (H_2, CO_2, and CH_4) to drive an electric generator to obtain electrical energy. Next, H_2 gas will be separated from other gases using a gas separator. The separated hydrogen gas is then stored in a hydrogen tank.

B. The Effectiveness of Corn Stover Waste Gasification Technology

The effectiveness of electricity and hydrogen production using corn stover waste gasification technology can be determined by calculating the fuel consumption rate, density of the mixture, the mass of gas from the gasification process, calorific value of gasification, gasification efficiency, amount of hydrogen and electricity produced, and CO_2 Emission Reduction Potential. Based on the calculations that have been done, for the gasification process of corn stover waste in East Lampung Regency, as much as 623,938.30 kg/year, the fuel needed for the combustion process is 71.225 kg/hour. The density of the mixture of corn stover waste is 0.556813 gram/cm^3. Then, the mass of gas produced from the gasification process is obtained from the multiplication of the density of the corn stover waste mixture with the total mass of the waste. The mass of gas produced is 347,416.956 kg. Furthermore, the heating value of the gasification process is 5,582,990 KJ/Kg, where the Lower Heating Value and Highest Heating Value of corn stover waste are respectively 16.07 and 18.18.

The efficiency of the corn stover waste gasification process using corn stover waste gasification technology is 49.219%. This efficiency is more significant when using updraft gasifier, downdraft gasifier, and cross- draft gasifier technology. Gasification efficiency using an updraft gasifier is 38.21%, a downdraft gasifier is 40%, and cross-draft gasifier efficiency is 21.86% (Mesliani, 2021). Then, the amount of electrical energy generated from corn stover waste in East Lampung Regency is 623,938.30 kg/year using using corn stover waste gasification technology, which is 15,550.831 kWh. Meanwhile, considering the average gasification efficiency value of 11.3%, the hydrogen produced reaches 34,363.69 liters. Using using corn stover waste gasification technology can help reduce carbon dioxide emissions which cause climate change because the utilization of corn stover waste into electricity and hydrogen, taking into account a biomass emission factor of 0.0008 is 11,980.36 tCO_2 annually.

C. Feasibility with Economic Analysis

Economic analysis is carried out with several parameters that begin with calculating capital expenditures or the cost of capital. Capital expenditure uses several assumptions, such as the cost of a steam turbine generator, gasifier, gas pipe, gas separator, power storage and hydrogen gas tanks. The amount of capital expenditure needed to build the Corn Stover Waste Gasification system is IDR 357,076,288.00. Then, the operational costs incurred during the operation process are also calculated. Cost Of Goods Sold (COGS) and Operating Expenses (OPEX). Cost Of Goods Sold in the first year reached IDR 572,398,920.00. This figure will continue to increase as production increases every year. OPEX needs in the first year reached IDR 368,707,628.80. So the total operational costs required in the first year of sales is IDR 941,106,548.80. This figure will continue to increase in line with the nominal COGS and OPEX yearly.

The estimated profit earned by corn stover waste gasification technology is determined based on the value of net earnings made each year. The net earnings obtained have gone through a complex financial analysis stage, considering the selling price of hydrogen products of IDR 30,000.00/liter and electricity of IDR 1,200.00/kWh, an increase in production every year (3%/year), an increase in COGS which adjusts the increase in production, the increase in operational expenditure, which adapts to the level of percentage increase in each of its parameters, up to 10 years of business continuity. From the analysis that has been done, net earnings in the first year amounted to IDR 108,444,251.08, in the second year of IDR 111,795,710.48, the third year in the amount of IDR 118,273,690.87, the fourth year in the amount of IDR

123,303,524.66, etc.

Corn stover waste gasification technology project's complex finances by calculating several economic parameters, such as the value of the payback period, Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit Cost Ratio (BCR). Some of these parameters can indicate the viability of corn stover waste gasification technology's business in the next few years. The revenue that will be obtained by corn stover waste gasification technology in the first year is IDR 1,049,550,997.20. This value is obtained from the profits derived from the sale of 34,363.69 liters of hydrogen products and 15,550.831 kWh of electricity. Revenue will continue to increase because there is a projected increase in product production by 3% every year.

Corn stover waste gasification technology achieved a payback period of 3,18 years. In the first ten years, the Net Present Value was IDR 424,840,321.31, and the Internal Rate of Return was 32% by applying a discount rate of 10%. NPV and IRR projections of businesses that show positive value and it makes corn stover waste gasification technology with products in the form of hydrogen and electricity a feasible business to implement in the long term (at least the next ten years). The corn stover waste gasification technology also has a benefit cost ratio (> 1), which is 1.02. The effectiveness.

CONCLUSION

Corn stover waste gasification technology with a calcium oxide (CaO) catalyst is an innovation in the gasification method, which has a high level of effectiveness in producing electricity and hydrogen energy from corn stover biomass in East Lampung Regency. Corn stover waste gasification technology is designed to be easier to implement and reduce production costs. Corn stover waste gasification technology is very promising to be projected as an investment object in the field of energy conversion because the fuel requirement for the corn stover gasification process of 623,938.30 kg/year is relatively low, which is 71.225 Kg/hour. Then, the mass of corn stover syngas is 347,416.956 kg. In addition, the effectiveness of corn stover waste gasification technology is relatively high, up to 49.219% in the biomass gasification process when compared to existing gasifier technologies such as an updraft type gasifier with an efficiency of 38.21%, a downdraft gasifier of 40%, and a cross draft gasifier of 21.86% (Mesliani, 2021).

Corn stover waste gasification technology has excellent economic feasibility. With complex financial projections, corn stover waste gasification technology achieves a payback period of 3,18 years, NPV of IDR 424,840,321.31, IRR of 32%, and BCR of 1.02. The use of corn stover waste gasification technology by utilizing corn stover waste is also able to help increase farmers' income from selling their agricultural waste as biomass. In addition, corn stover waste gasification technology can reduce carbon dioxide emissions by 119,803.6 tCO_2 in 10 years by utilizing agricultural waste for electricity and hydrogen energy. Therefore, with the use of corn stover waste gasification technology in East Lampung Regency, optimizing biomass as renewable energy can support the realization of local community prosperity and the 2030 Sustainable Development Goals.

REFERENCES

Al-afifi, U. F., Erdin Syam, & Elvin Piter. 2021. Calculation of Potential Electrical Energy in Rice Husk Through the Gasification Method. *SainETIn*, *4*(2), 48–56.

Arinaldo, D., Mursanti, E., & Tumiwa, F. 2019. Implications Of The Paris Agreement For The Future Of Coal- Fired Power Plants in Indonesia. *Accelerating Low-Carbon Energy Transition*, *96*(3), 445.

Boer, Rizaldi., Dewi, R. 2018. *Indonesia Second Biennial Update Report Under the United Nations Framework Convention on Climate Change*.

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. 2014. Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews*, *39*, 748–764.

Florin, N., & Fennell, P. 2011. Synthetic CaO-based Sorbent for CO_2 Capture. *Energy Procedia*, *4*, 830–838.

Kim, C., Kim, J., Joo, S., Bu, Y., Liu, M., Cho,J., & Kim, G. 2018. Efficient CO_2 Utilization via a Hybrid Na-CO_2 System Based on CO_2 Dissolution. *IScience*, *9*, 278–285.

Li, B., Yang, H., Wei, L., Shao, J., Wang, X., & Chen, H. 2017. Hydrogen production from agricultural biomass wastes gasification in a fluidized bed with calcium oxide enhancing. *International Journal of Hydrogen Energy*, *42*(8), 4832–4839.

Lund, H., Skov, I. R., Thellufsen, J. Z., Sorknæs, P., Korberg, A. D., Chang, M., Mathiesen, B. V., & Kany, M. S. 2022. The role of sustainable bioenergy in a fully decarbonised society. *Renewable Energy*, *196*, 195–203.

Mahmoudi, A. 2015. *Prediction Of Heat- Up, Drying And Gasification Of Fixed And Moving Beds By The Discrete Particle Method (DPM)* (Vol. 1, Issue 1).

Mesliani. 2021. *Design of Integration of Plastic Pyrolysis Equipment and Biomass Gasification*.

Nzihou, A., Stanmore, B., & Sharrock, P. 2019. A Review Of Catalysts For The Gasification Of Biomass Char, With Some Reference To Coal. *Energy*, *58*, 305–317.

Siswati, T. I. N. D. 2012. Utilization Of Agricultural Waste As An Alternative Energy Through Thermal Conversion. *Buana Sains*, *12*(1), 117–122.

Slameto. 2021. Study on production of several soybean varieties with corn intercropping system on dry land in East Lampung , Lampung Province Study on production of several soybean varieties with corn intercropping system on dry land in East Lampung , Lampung Province. *ICALS 2020*, 1–12.

Tari, A. 2020. *Pre Design Of Active Charcoal Factory From Corn Corn With A Capacity Of 3,900 Tons/Year.*