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Evaluating the Potential of Hydrogen Production from Agricultural Waste in Indonesia: A Comparative Techno-economic Analysis

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ABSTRACT

Hydrogen production from agricultural waste is a potentially established industry in Indonesia, and the government aims to introduce innovative technologies to produce hydrogen. This study aimed to explore the feasibility of hydrogen production from agricultural waste using three different methods: SCWG, fermentation, and gasification. The analysis focuses on comparing the price of hydrogen as a product by setting the same value of the IRR at 30%. The simulation was conducted by analyzing the capacity of hydrogen production at 3650 tons/year. The results of this study demonstrate that fermentation is the most feasible technology for producing hydrogen from agricultural wastes in Indonesia. In this technology, the price of hydrogen obtained was $5.65/kg, with a total capital investment (TCI) and production cost (TPC) of $10,756,132.97 and $13,977,351.97, respectively. Based on this simulation, the other parameter values, including NPV, ROI, and PoT, were $15,387,688.72, 68%, and 2.27 years, respectively. These results indicate that the establishment of hydrogen production in Indonesia using fermentation technology and agricultural waste is economically viable.

Keywords: Agricultural Waste, Hydrogen, Renewable Energy, Techno-economic Analysis
JEL Classifications: Q1, Q2, Q4

1. INTRODUCTION

Hydrogen is a renewable energy source in Indonesia with various applications, including as feedstock for chemical production, transportation fuel, and energy sources for power plants (Al-Fatesh et al., 2023; Erbach and Jensen, 2021; Grecea et al., 2021; Sampaio et al., 2022). It can be produced from organic materials such as agricultural waste through various transformation procedures (Borgogna et al., 2022; Chari et al., 2023; Li et al., 2010; Łukajtis et al., 2018; Megia et al., 2021; Ozturk and Dincer, 2021). The production of hydrogen from organic waste has the potential to create an industry with a net zero carbon output (Pawelczyk et al., 2022). This can help to boost the development of clean energy by efficiently converting methods and eliminate the negative impact of industrial production on the environment (Bessarabov and Pierre Millet, 2018; Ishaq et al., 2022).

Indonesian government has recently proposed a plan to transition away from fossil fuels and towards the use of hydrogen as a sustainable and environmentally friendly energy source (Humas EBTKE, 2022a). This initiative is expected to reduce the negative impacts of fossil fuel use on ecology, climate change, the environment, and human health (Lelieveld et al., 2019; Younas et al., 2022). Although the use of hydrogen as a substitute for fossil fuels has the potential to significantly reduce carbon dioxide emissions produced by industry, several obstacles must be overcome, including a lack of financial and public support, as well as the need for government policies that support the use of renewable energy sources in Indonesia (Humas EBTKE, 2022b).

Agricultural waste products have been identified as potential sources of hydrogen production. Liu et al. (2017) conducted research to determine the feasibility of producing hydrogen from food scraps, bovine manure, potato pulp, and pig manure. This study found that a specific mixture of these waste products has the potential to generate hydrogen with a yield of 21 mL/g. Karaeva (2021) found that steam catalytic conversion technology can generate 107,341 kg of hydrogen per day using 4.4 million tons of agricultural waste annually. Ayas and Çağlı (2021) demonstrated that using a catalyst consisting of 20 wt% nickel and bentonite can produce 5.31 mol/kg of hydrogen from agricultural waste. These findings suggest that hydrogen production from agricultural waste is a feasible alternative to fossil fuels.

The production of hydrogen from agricultural waste can be achieved using several approaches, including supercritical water gasification (SCWG), fermentation, and conventional gasification. SCWG is a novel process that can convert a variety of organic wastes into hydrogen without a drying step (Okolie et al., 2019). Fermentation is a cost-effective method for converting biomass to hydrogen (Karadag et al., 2014), and processing agricultural waste through fermentation offers several benefits such as being environmentally friendly, renewable, and biodegradable (Guo et al., 2010). Conventional gasification is also a well-known method for converting waste from agricultural operations into hydrogen (Demirbaş, 2002; Hamad et al., 2016; Karellas, 2015), and it is considered one of the most efficient and effective methods for producing hydrogen (Karellas, 2015; Parthasarathy and Narayanan, 2014).

A techno-economic study is crucial for converting Indonesia's agricultural waste into hydrogen, which requires estimation of capital costs, operational costs, and projected income (Burk, 2018). This analysis serves as a basis for further examination of the technologies available in Indonesia for processing agricultural wastes. However, no studies have compared the economic viability of various hydrogen production technologies. The objective of this study was to evaluate the economic feasibility of producing hydrogen from agricultural waste using three distinct methods (SCWG, fermentation, and gasification). The primary focus of this investigation is the comparison of hydrogen sales at equal internal rate of return (IRR) values for each method. To gain better insight into the impact of hydrogen sales on economic factors, a sensitivity analysis was also conducted.

2. RESEARCH METHODOLOGY

2.1. Purchase Equipment Cost Estimation

Equipment pricing was established based on information collected from multiple investigations into SCWG, fermentation, and gasification technology for hydrogen generation (Han et al., 2016; Parks et al., 2011; Shi et al., 2023). The corresponding potential economic benefits (PEC values) are presented in Table 1.

Table 1: The purchase equipment cost in producing hydrogen from different technology

Technology	Capacity (tons/year)	PEC	Year	References
SCWG	730,000	$ 668,074,000	2019	Shi et al. (2023)
Fermentation	1095	$ 1,789,900	2015	Han et al. (2016)
Gasification	730,000	$ 565,400,000	2016	Parks et al. (2011)

SCWG: Supercritical water gasification

Based on the information presented in Table 1, a comparative analysis was conducted between the conventional six-tenth rule and the Chemical Engineering Purchase Cost Index (CEPCI) to determine the estimated PEC hydrogen production for a capacity of 3,650 tons of hydrogen per year in 2024. To achieve this objective, Equation 1 was used for the calculations.

$$PEC_{aX} = \left(\frac{CEPCI_X}{CEPCI_Y}\right) \times \left(\frac{Cp_a}{Cp_b}\right)^{0.6} \times PEC_{bY} \quad (1)$$

Data regarding agricultural waste in Indonesia were sourced from various publications to determine the probability of raw material availability for hydrogen production. Based on the information obtained, an estimate of the amount of agricultural waste in 2024 was made in this analysis.

The feasibility of the plant can be assessed through an evaluation of economic factors, utilizing four indicators to examine the viability of hydrogen generation in Indonesia. These criteria are net present value (NPV), return on investment (ROI), payout time (PoT), and internal rate of return (IRR).

2.2. Net Present Value Estimation

According to McAuliffe (2015) and Sullivan et al. (2019), the net present value (NPV) is the difference between annual inflows and outflows presented in current value terms. This evaluation is conducted for the purpose of providing a reference for an investment project. The NPV value can be determined using Equation 2.

$$NPV = Z_0 + \sum_{j=1}^{j=n} \frac{M_j}{(1+i)^j} \quad (2)$$

Where Z_0 is the initial cash flow, M_j is the annual cash flow, j is the year of investment, and i is the minimum attractive rate of return (MARR). In this study, the value of i is set to 10%.

2.3. Return on Investment Estimation

Return on investment (ROI) is a fundamental concept that quantifies the profitability of an investment by assessing the rate of return on investment (Chuke Nwude, 2012; Sullivan et al., 2019). The ROI was calculated using Equation 3.

$$ROI = \frac{Annual\ Sales - Annual\ Production\ Cost}{Fixed\ Capital} \quad (3)$$

2.4. Payout Time Estimation

The payout time, denoted as PoT, represents the estimated year in which the investment commences profit generation. It is a crucial factor in the assessment of the viability of an investment in this industry (Aries and Newton, 1955; Sullivan et al., 2019). In this year, the profits earned by the plant in the current year are expected to cover the initial capital outlay required for the industry's development. Equation 4 can be utilized to determine the PoT.

$$PoT = \frac{Fixed\ Capital}{Annual\ Profit + Annual\ Depreciation} \quad (4)$$

2.5. Internal Rate of Return

The internal rate of return (IRR) is a method employed to assess the viability of an investment. This analysis involves considering all cash flow aspects and the present value of money over time. The estimation of IRR is calculated by equating the present value of future cash inflows to the cost of the investment, as determined by Equation 5 (Feibel, 2003; Renies et al., 2016).

$$0 = \sum_{n=0}^{N} \frac{C_n}{\left(1 + IRR\right)^n} \quad (5)$$

Where C_n is the net annual cash flow in year n, the values of PoT and IRR are crucial because they are generally used to evaluate the economic feasibility of an industry (Azis et al., 2021).

This investigation concluded that an internal rate of return (IRR) of 30% would be suitable for assessing the feasibility of three different methods of generating hydrogen in Indonesia. By using this approach, a calculation was made to compare the costs of hydrogen at various techonologies while maintaining a constant IRR. The algorithm utilized in this calculation is presented in Figure 1.

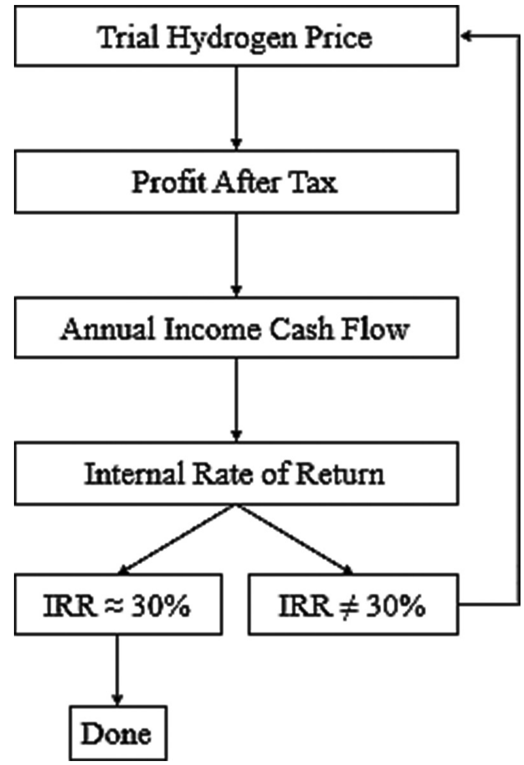
3. RESULTS AND DISCUSSION

3.1. The Calculation of Capital and Operating Cost

In this techno-economic analysis, we examined three methods for producing hydrogen from agricultural waste: supercritical water gasification (SCWG), fermentation, and gasification. These technologies are commonly employed in the processing of waste to produce chemical products, such as fuel. Our study found that the capacity for hydrogen production from agricultural waste was the same across all methods, at 3650 tons. Additionally, approximately 3041.67 tons of agricultural waste were converted annually. This quantity of waste is consistent with the annual availability of agricultural waste sources in Indonesia, which is estimated to be around 7563 tons (Budhijanto et al., 2019; De Lima and Patty, 2021).

The present study calculated the PEC values for various technologies using Equation 1, with the CEPCI pricing index for the year 2024 serving as the benchmark for price evaluation to ensure the accuracy of the study. However, it should be noted that the cost of the required land was not taken into consideration in these estimates. To determine the FCI for each technology, it was assumed that the PEC value would equal 40% of the FCI (as proposed by Peters et al. (2003)). The calculated PEC and FCI values for each technology are presented in Table 2 below.

Figure 1: The algorithm for hydrogen price calculation



The operating costs associated with the production of hydrogen require a comprehensive assessment, which includes factors such as feedstock expenses, employee salaries, and maintenance costs. While the cost of waste from the agricultural sector is assumed to be zero, a price of $0.17 per kilogram has been estimated for the constant flow of waste collection and transportation. The remaining expenditures have been calculated based on information provided by Sinnot et al. (2005), and the results of these calculations are presented in Table 3.

Based on the results of this investigation, it was determined that the allowances for general expenses and working capital should be allocated 20% of operational costs and 10% of investments in fixed assets, respectively. This analysis enabled the estimation of the total capital investment (TCI) and total production cost (TPC) for each technology, as presented in Table 4.

3.2. Economic Feasibility Analysis

In this investigation, the lifespan of a hydrogen-producing plant was estimated to span 11 years, with the first 10 years dedicated to the productive process and the final year dedicated to construction. Upon completion of the operational phase, it was projected that the salvage value of the plant would account for 10% of the FCI. As depicted in Figure 2, the cash flow generated by the plant over its entire lifecycle was considered.

Based on the cash flow diagram, it is feasible to determine several significant economic parameters, including NPV, ROI, PoT, and IRR. Using the presented algorithm in Figure 1, the IRR can be calculated at 30%, which is included in Table 5. The table displays the results of the calculation.

Table 2: The value of PEC and FCI for each hydrogen production technology

Technology	CEPCI reference year	CEPCI 2024	PEC	FCI
SCWG	611.82	659.14	$ 26,856,615.82	$ 67,141,539.54
Fermentation	556.80		$ 3,911,321.08	$ 9,778,302.70
Gasification	541.70		$ 28,638,772.44	$ 71,596,931.10

CEPCI: Chemical Engineering Purchase Cost Index, SCWG: Supercritical water gasification

Table 3: The operating cost of 3650 tons of hydrogen/year production in Indonesia

Operating cost				
Fixed operating cost	**SCWG**	**Fermentation**	**Gasification**	**Detail proportion (%)**
Maintenance	$ 6,714,153.95	$ 977,830.27	$ 7,159,693.11	10% FC
Operator/workers	$ 552,576.00	$ 552,576.00	$ 552,576.00	
Laboratory	$ 110,515.20	$ 110,515.20	$ 110,515.20	20% workers
Supervisor	$ 110,515.20	$ 110,515.20	$ 110,515.20	20% workers
Plant overhead	$ 276,288.00	$ 276,288.00	$ 276,288.00	50% workers
Depreciation/capital charges	$ 6,714,153.95	$ 977,830.27	$ 7,159,693.11	10% FC
Insurances	$ 671,415.40	$ 97,783.03	$ 715,969.31	1% FC
Property taxes	$ 1,342,830.79	$ 195,566.05	$ 1,431,938.62	2% FC
Royalties and patents	$ 2,437,593.40	$ 412,718.42	$ 2,597,879.04	2% sales
Total	$ 18,930,041.89	$ 3,711,622.44	$ 20,115,067.59	
Variable cost	**SCWG**	**Fermentation**	**Gasification**	**Detail proportion**
Raw materials	$ 518,032.41	$ 518,032.41	$ 518,032.41	
Plant supplies	$ 671,415.40	$ 97,783.03	$ 715,969.31	10% maintenance
Utilities	$ 671,415.40	$ 97,783.03	$ 715,969.31	10% maintenance
Packaging and shipping	$ 42,657,884.43	$ 7,222,572.40	$ 45,462,883.15	35% sales
Total	$ 44,518,747.63	$ 7,936,170.86	$ 47,412,854.18	
Total operating cost	$ 63,448,789.52	$ 11,647,793.31	$ 67,527,921.77	

SCWG: Supercritical water gasification

Table 4: The operating cost of 3650 tons of hydrogen/year production in Indonesia

Technology	TCI	TPC
SCWG	$ 73,855,693.50	$ 76,138,547.42
Fermentation	$ 10,756,132.97	$ 13,977,351.97
Gasification	$ 78,756,624.21	$ 81,033,506.13

TCI: Total capital investment, TPC: Total production cost, SCWG: Supercritical water gasification

Based on the findings in Table 5, the price of hydrogen produced through fermentation technology at an IRR of 30% is significantly lower than the other methods. This suggests that fermentation is a viable option for producing hydrogen from agricultural waste. The economic study results show that the NPV value for fermentation is positive, indicating that hydrogen generation through this technology is feasible. In addition, the value of ROI before tax is 68%, fulfilling a good investment's minimum ROI value of 4% (Aries and Newton, 1955; Sullivan et al., 2019).

3.3. The Calculation of Breakeven Point (BEP) and Sensitivity Analysis

It is important to perform a breakeven point (BEP) calculation to determine the minimum capacity required to achieve an equal value between overall income and production costs. If the plant operates at a capacity below this point, it will result in a loss. Therefore, it can be concluded that BEP is a crucial requirement for a plant to be profitable. As depicted in Figure 3, the calculated value of BEP for producing hydrogen from agricultural waste using the fermentation method is 60%. According to Aries and Newton (1955), an investment is considered attractive if the value of BEP is ≤60%.

Figure 2: The Cashflow diagram of hydrogen plants from agriculture waste in Indonesia

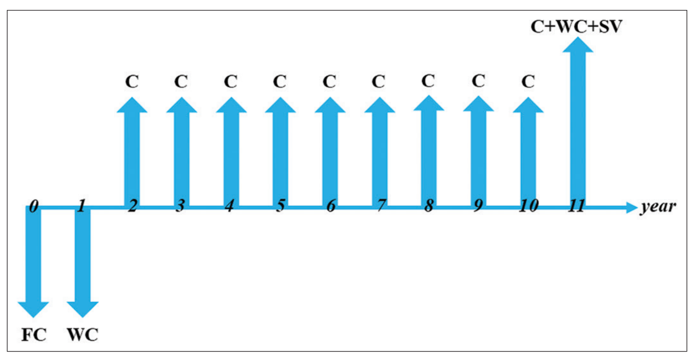
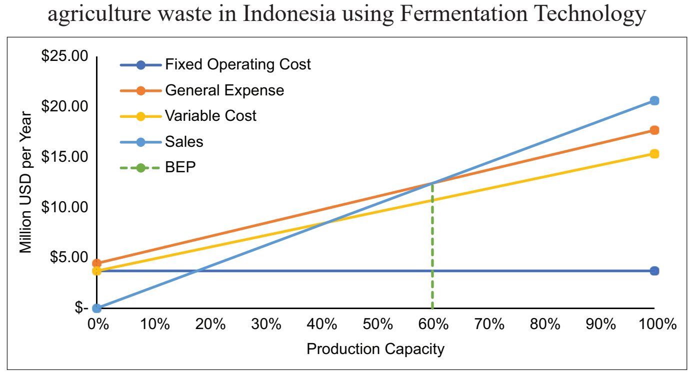


Figure 3: Breakeven point diagram for hydrogen production from agriculture waste in Indonesia using Fermentation Technology



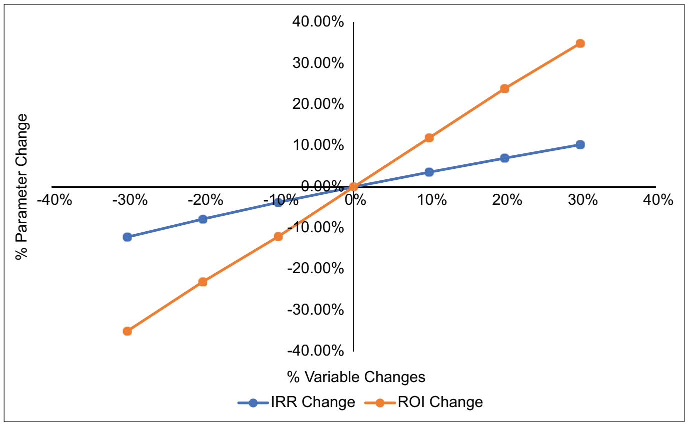
The cost of hydrogen is a significant factor in the context of fermentation technology, and it is essential to perform a sensitivity

Table 5: The value of economic parameters for each hydrogen production technology

Technology	IRR (%)	NPV	ROI before tax (%)	PoT (years)	Hydrogen price
SCWG	29.96	$ 105,719,292.90	68	2.27	$ 33.39
Fermentation	29.95	$ 15,387,688.72	68	2.27	$ 5.65
Gasification	30	$ 112,982,701.45	68	2.27	$35.59

IRR: Internal rate of return, NPV: Net present value, ROI: Return on investment, PoT: Payout time, SCWG: Supercritical water gasification

Figure 4: The Sensitivity Analysis of Hydrogen Price to the Value of ROI and IRR



analysis that considers changes in hydrogen prices in order to fully comprehend the influence of fluctuations in hydrogen pricing on the return on investment (ROI) and internal rate of return (IRR). The study at hand examines the dynamic nature of hydrogen pricing and its effect on these financial metrics, as depicted in Figure 4. Significant changes in the value of ROI and IRR are observed whenever the price of hydrogen undergoes modification. This, in turn, impacts investor interest in the sector. As a result, it is imperative to maintain the stability of hydrogen prices not only in the production process but also in the supply chain to sustain the continuity of hydrogen-generating plants that rely on agricultural waste.

4. CONCLUSION

The production of hydrogen from agricultural waste is a challenge that must be addressed to support the development of renewable energy in Indonesia. The Indonesian Government has set a goal to produce green energy to reduce the negative impact of pollution on the environment and protect human health. This study presents a feasibility economic study of hydrogen production from agricultural waste using several methods that have been developed. The analysis indicates that fermentation is the most cost-effective method for producing hydrogen, with a low-cost price and good income. The internal rate of return (IRR) of the production was set at 30%, and the lowest price of hydrogen production was offered by fermentation technology at $5.65/kg. The total capital investment required to build a plant using the fermentation method is $10,756,132.97, with a total production cost of $13,977,351.97. The annual revenue is $20,635,921.14. The development of this technology has a net present value (NPV) of $15,387,688.72, a return on investment (ROI) of 68%, and a payback period (PoT) of 2.27 years.

These parameters indicate that investing in this technology is profitable in Indonesia. It is also important for the Government to manage the price of hydrogen to maintain stability in the hydrogen industry from agricultural waste. Further research is needed to optimize the fermentation process for hydrogen production and to create a detailed calculation of the process to ensure its sustainability in Indonesia.

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