Cost Estimation of Hydrogen Generation from Palm Oil Waste via Supercritical Water Gasification

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Abstract

This study focuses on the economic viability of converting oil palm waste, particularly empty fruit bunch (EFB), to hydrogen via supercritical water gasification (SCWG). Biomass supercritical water gasification technology remains in R&D stage and commercial plants have yet to exist. Many studies have performed analysis on the technical aspects but few works study the economic aspects of such technology, which is also vital for commercialization. Moreover, cost analysis varies greatly with different assumptions and considerations. With respect to this, our work estimated the cost of a supercritical water gasification plant in Malaysia.

Keywords: Oil palm waste, EFB, supercritical waster gasification, hydrogen, cost

1. Introduction

Since the extensive plantation of oil palm, palm oil has become the most profitable product in South East Asian countries, especially Malaysia and Indonesia. Indeed, oil palm has significant impacts on the structure of the environment, agriculture, and economy. However, the large yield of lignocellulosic based residues, such as empty fruit bunches (reaching around 4.42 tonne per ha/year), oil palm trunks, oil palm fronds etc., is associated with major environmental problems. If burnt directly, empty fruit bunches (EFB) with its high volatile content at 70%, (see Table 1.) will emit excessive 'white smoke' and thus is not a preferable disposal method. As the importance of hydrogen increase for fuel cell application, a prominent technology — supercritical water gasification (SCWG) can be employed to convert high water content biomass to valuable products. At supercritical water condition (P>22 MPa, T> 374 °C), water behaves like a non-polar organic single-phase solvent, allowing many organic compounds and gases can be dissolved in it. Two main reactions are involved: glucose steam reforming and water-gas shift reactions to form a hydrogen and methane rich gas. Another advantage is its high gasification efficiency. The gasification process takes place in only one reactor, producing a high molar fraction of hydrogen in the gaseous products, meaning less cost for separation of the hydrogen from product gas. A pilot plant of this technology pilot plant is demonstrated in Germany in 2007 with a capacity of 100 kg/hr.

Table 1. Empty Fruit Bunch Characteristics

Proximate analysis*	wt%	Ultimate analysis**	wt%
Moisture	5.84	C	53.22
Ash	13.65	H	6.25
Volatiles	70.03	N	0.97
Fixed carbon	10.48	S	0.48
Total	100	O***	39.08
Calorific value* (MJ/kg)	17.61		

*As received; **Dry and ash free basis; ***from difference.

2. Project Assumptions

The plant is set to be installed next to a palm oil plantation site in Malaysia, and since the waste is provided on-site by the owner of the plant, no feedstock cost and shipping fee to the plant are considered. The operating time is 8000 hr/yr (92% availability, 1 month for suspended annual maintenance) with plant capacity: 144 mt/day and hydrogen yield rate: 10 g H_2/per 100 g feed, which leads to 4800 mt of H2/ year. According to the recommendation of a 2011 National Renewable Energy Laboratory (NREL) report, we set the plant life to be 20 years and an appropriate depreciation schedule of 7 years. Since supercritical water gasification technology requires a high pressure to operate, the cost of electricity and water cannot be ignored and thus are purchased in this study. For financial assumptions, we assume the plant is 100% equity financed, and the central bank interest rate of Malaysia is 3 %. With potential hydrogen sale price could range from $ 3-10 /kg, here we set the sale price at a competitive price with other hydrogen generation technologies, $ 3.5 /kg. A simplified process flowchart is illustrated below:

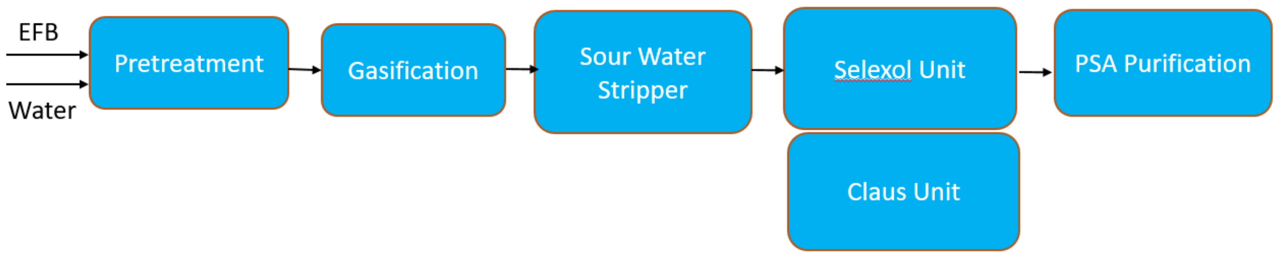

Figure 1. SCWG Process Flowchart

The process consists of a number of unit operations such as feed crushing, pumping & pressurizing, heat exchanging, gas-liquid separation and hydrogen purification. The major processes are based on Aspen Plus simulation in 2013 Langè's work. To meet the stringent emission standard nowadays, syngas cleaning units are applied to achieve carbon dioxide and sulfur free product gas. In the figure, sour water stripping refers to stripping hydrogen sulphide and ammonia from refinery sour water prior to subsequent reuse or wastewater treatment. The Selexol Unit is a physical sorbent-based acid gas removal of hydrogen sulfide and carbon dioxide from feed gas streams such as synthesis gas produced by gasification. In the Claus Unit, high H_2S concentration stream serves as the feedstock for recovery to elemental sulfur. Lastly, the Pressure Swing Absorption Unit (PSA) is for hydrogen purification.

3. Cost estimation methodology

This study aims to calculate the following important indicators to gauge profitability: internal rate of return (IRR), cost of hydrogen per unit and payback time. We only consider the direct manufacturing costs, which includes the fixed capital cost of a plant (land, tax, labor, administration and patent costs not taken into account), and the variable operation and maintenance costs. The total variable costs were calculated at 6% of the total capital costs (based on the 2010 NREL's report) due to the difficulty of procuring electricity and water consumption data of an actual operating plant. Additional costs of distribution and sales of hydrogen are not considered either.

- Total Cost = Fixed Cost + Variable Operations and Maintenance Cost (VOM)

1. Fixed: Equipment
2. VOM: Materials (e.g. solvents and catalysts), electricity and water consumption, etc.

The following are calculated to obtain the final results:

- Internal Rate of Return (IRR): Interest rate that is required to bring the net present value to zero.
- Payback time: Dividing the initial investment cost by its annual expected cash inflow.
- Gross profit = Sales – cost of goods sold
- Net income = Gross profit – operating expenses

4. Results and discussion

If a hydrogen selling price of $ 3.5/kg is employed, the annual income will be as high as $8,827,714. The annual cash flow will be $14,442,000 and the payback time is around 2.72 years. The internal rate of return turns out to be 31% which is much higher than the central bank interest rate of 3% in Malaysia. The cost is greatly reduced in this study since feedstock cost is not considered. If considering the cost of EFB at a price of 15 USD/tonne, then the total cost for each year will increased by: 144 mt/day*365days/yr*$15/mt=$ 788400, which leads to cash flow: $ 13,653,600/yr, net income: $ 8,039,314/yr and payback time 2.9 years. This result shows that owing to the cheap price of feedstock, it doesn't make too much a difference for profitability.

Table 2. Cost Summary

SCWG Biomass-to-Hydrogen Scenario Summary
144 Metric Tonnes Biomass per Day
Product Yield: 10 g hydrogen / 100 g feed
Product Value ($/kg): 3.5 USD
Plant life: 20 years, Depreciation: 7 years

Availability: 92%, operating 8000 h/yr Equity Percent of Total Investment 100%				
Capital Costs		**%**	**Operating Costs**	
Process Units			Electricity (0.1$/kWh)	N/A
[Pretreatment] crusher/conveyor/slurry pump	$1,000,000	2.5	Water (0.26$/per cubic meter)	N/A
[Gasification] SCW Reactor	$12,000,000	30.5	Catalysts (NaOH, K and Ni) & Solvents	N/A
[Sour Water Stripper] Water Treatment	$6,900,000	17.6	Maintenance & Other	N/A
[ClausUnit] Sulfur Recovery	$8,900,000	22.6	**Total Operating and Maintenance (O&M) Costs** [6 % of capital cost/yr]	$2,358,000
[Selexol Unit] CO_2 H_2S Removal	$10,000,000	25.4	**Cost of H2 per unit**	$ 1.66/kg
[PSA] Hydrogen Purification	$500,000	1.3	**Net income/yr**	$8,827,714
Total Capital Costs	$39,300,000		**Cash flow/ yr**	$14,442,000
			Payback Time	2.72
			Internal Rate of Return	31%

The scope and results of this study is compared other similar works in the literature as Table 3.

Table 3. Comparison with Previous Techno-Economic Studies of Biomass-Gasification Plants

	NREL report 2011 [2]	Stefano Langè et al. 2013 [1]	Yukihiko Matsumura et al. 2002 [4]	This Study 2016
Feedstock biomass type	wood and others	EFB	water hyacinth	EFB
Plant Capacity [ton per day: tdp]	1st: 500 Nth: 2000	336	1	144
H2 production [mt/y]	150,000	14,900	3.05 yen/MJ	4,800
Investment cost [million usd]	1st: 214 Nth: 334	41.4	2.4	39.3
Income [million usd]	N/A	12.5	N/A	8.8
Payout time [year]	N/A	3.79	CO2 payback 4.19	2.72

Hydrogen Cost ($/kg)	1st plant (500 tpd): 5.4 Nth plant (2000 tpd): 2.8	N/A	N/A	1.66
Remark	Non-SCWG Feedstock bought	SCWG Feedstock and power self-sufficient	SCWG Fuel and electricity self-sufficient	SCWG Purchase water and electricity Feedstock self-sufficient

5. Conclusions

The results of this work show that supercritical water gasification is a profitable technology for the efficient conversion of wet biomass. It is a viable option for empty fruit bunch disposal to be implemented in Malaysia. However, the accuracy of this cost estimation leaves much to be improved with supplement of more recent, first-hand data. In addition, several technical challenges for the still immature SCWG technology, including thermal efficiency, plugging and corrosion problems, still need to be overcome in order to enter the market.

Acknowledgments

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