Research article

The Study of Greenhouse Gas Emissions of Ethanol Production from Agro-industrial Fruit Residues

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Abstract Nowadays, bio-ethanol is playing an important role as an alternative fuel for passenger cars in Thailand. The use of biofuel can reduce greenhouse gas (GHG) emissions because it is derived from plant materials. This study aimed to analyze greenhouse gas (GHG) emissions of ethanol production from agro-industrial fruit residues based on a life cycle approach. The results showed that the life cycle GHG emissions of ethanol production were found to be 123.10 kg CO_2-eq/kg of anhydrous ethanol. The main source of GHG emission was the electricity used in the process stage (97.83%) and the second was materials and reagents used in the stage (2.64%). It showed major energy consumption came from the conversion process to produce ethanol. Another encouraging result is that 1 kg non-pretreated pineapple peel waste inputs could produce 525 g of ethanol fuel; or it is was estimated to be 52-53% of ethanol production. Therefore, agro-industrial fruit residues can be feedstock for ethanol production in Tropical countries.

Keywords LCA, GHG, ethanol, pineapple peel waste

INTRODUCTION

Biofuels are important because they replace petroleum fuels. The emissions of greenhouse gases (GHGs), in particular carbon dioxide (CO_2), are expected to reduce when fossil fuels are replaced with biofuels; because the latter are derived from plant materials. Bioethanol is by far the most widely used biofuel for transportation worldwide. Ethanol utilization for sustainable energy in this decade is desired especially ethanol produced from agricultural waste. The reason is, in the sense of economy and environmental prevention, it can reduce greenhouse effects. There are studies on ethanol production from agricultural waste such as sweet sorghum bagasse, cassava waste, rice straws, and pineapple peel waste, which are renewable and interesting resources (Itelima et al., 2013; Nigam, 1999; Siwarasak et al., 2006; Siwarasak et al., 2012; and Wang et al., 2012). Ethanol production is an alternative energy that can solve environmental impact and a value added form of solid-waste for agricultural industries, particularly in Thailand. The bioconversion of cellulose and hemicelluloses to monomeric sugars, for example, carbohydrates with 5 and 6 carbons are harder to accomplish than the conversion of starch, presently used for bioethanol production (Ohgren et al., 2006). There are several options for a lignocelluloses-to-bioethanol process, which is chosen. However, a few data on an environmental analysis of bioethanol production from agro-industrial fruit residues have been reported. The cassava waste and rice straws are high potential raw materials to produce ethanol from fermentation. Moreover, pineapple peel is a potential raw material to produce ethanol due to its containing an appreciable amount of insoluble fiber-rich fraction, which primary consists of cellulose, pectin substances, hemicelluloses, and notable proportions of lignin (Huang et al., 2011). According to Thai Office of

Agricultural Economics, Thai pineapple products in 2011 were increased by 25.41% compared to the previous year (OIE, 2012). The products mostly included fresh pineapples and processed pineapple products. Canned pineapple processing industry is one of the highest potential industries in Thailand, due to its geography of locating in monsoon region. The skins, cores, and ends of a pineapple are not discarded in pineapple canneries but instead used to make a number of products such as vinegar, alcohol, and animal food. Thailand is ranked as the top of the pineapple exporting countries with a market share of 40-50% (Eapsirimetee et al., 2013). Table 1 shows the 2015 forecasting of farm crop perennial trees and fruit trees in the whole kingdom including harvested areas, productions, and yield of pineapple (OAE, 2015). Furthermore, an analysis of supply or productivity of pineapple in Thailand is also reported in the table. Pineapple peel, a by-product of the pineapple processing industry, account for 29-40% (w/w) of total pineapple weight (Choonut et al., 2014). From Table 1, this implies a high potential of using pineapple peel for ethanol production.

Table 1 Forecasting of farm crop perennial trees, fruit trees and pineapple productivity in Thailand

Pineapples	Year			Quantity	Percent
	2013	2014	2015	±	±
Harvested areas (rais)	532,947	479,072	476,433	-2,639	-0.55
Productions (tons)	2,067,908	1,748,222	1,702,735	-45,487	-2.60
Yield (kgs/rai)	3,880	3,649	3,574	-75	-2.06

OBJECTIVES

The aim of this study was to investigate the impact of bioethanol production by fermentation from agro-industrial fruit residues with *Trichoderma reesei* RT-P1 and *Saccharomyces cerevisiae* RT-P2 to the environment and to promote the use of indigenous and renewable sources for transportation fuels. Life cycle assessment (LCA) was carried out to determine the GHG emissions performance. Bioethanol from pineapple peel wastes in Thailand was considered in the analysis.

METHODOLOGY

Life cycle assessment (LCA) was used as an environmental assessment tool to identify and evaluate the GHG emissions of bioethanol production from agro-industrial fruit residues (pineapple peel wastes). LCA methodology used in this study was based on ISO 14040 framework, which consisted of four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation (Lee and Inaba, 2004). The life cycle inventory analysis and impact assessment were carried out based on ISO 14040 for all stages involved in the production of 1 kg of 99.5% ethanol (anhydrous ethanol) from pineapple peel wastes which included transportation and bioethanol conversion, but not cultivation and harvesting. The functional unit (FU) of this study was 1 kg of 99.5% ethanol production. The system boundary is shown in Fig. 1. Most of input-output data were collected as primary data at the actual sites in Thailand. These collected data included raw materials used, energy consumption, utilities, and waste generated within the system boundary. The secondary data were used in this study as necessary from literatures, calculation, etc. The analyses focused on the three most important GHGs of bioenergy systems including i.e. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), with the global warming potential factors of 1, 25, 298 kg CO_2-eq/kg substance, respectively (IPCC, 2007).

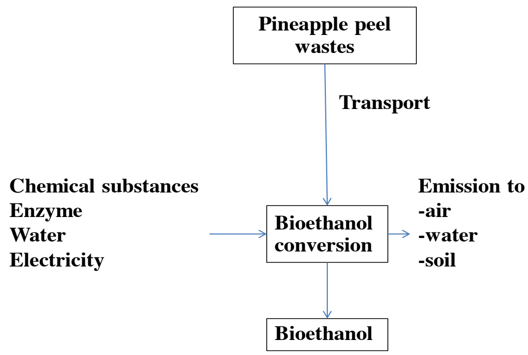

Fig.1 Product system boundary of this study

Preparation of Raw Materials and Transportation

In this study, pineapple peel waste was tendered by United Winery and Distillery Company limited, Nakhon Chai Si, Nakhon Pathom province, Thailand. Pickup Trucks with load 560 kg transported pineapple peel wastes from the factory to Chemical Engineering Laboratory. The laboratory is located in Rajamangala University of Technology Thanyaburi, Pathumthani province, Thailand. The transport distance was 200 km (round trip). The data were collected at the sites. Diesel fuel consumption was 24.5 L per 200 km (Table 2). The samples were dried before performing the experiment.

Bioethanol Conversion

Based on the optimal fermentation conditions obtained from analysis results of orthogonal experiment, the verification of ethanol conversion was obtained from fermentation by using crude enzyme powder. Crude enzyme powder was produced from co-culture of *Trichoderma reesei* RT-P1 and *Saccharomyces cerevisiae* RT-P2. The ethanol fermentation was carried out in 250 mL shaking flasks at 120 rpm, by using 8% dried weight of pineapple peels in 100 mL liquid medium for 1 to 5 days cultivation at initial pH 5 at room temperature (30 ^{o}C). Samples were collected daily for analysis of ethanol and reduced sugar concentration. Ethanol concentrations were estimated by the dichromate colorimetric method (Williams and Reese, 1950), and the reduced sugar concentrations were estimated to be 3, 5-dinitrosalicyclic acid (Miller, 1959). Three replications were done in this experiment.

RESULTS AND DISCUSSION

Ethanol batch fermentation from pineapple peels wastes with the crude enzyme powder was analyzed. The results of batch fermentation are shown in Fig. 2. From the figure, ethanol concentration was initially around 8 g/L for batch fermentation. Ethanol values increased to 42 g/L on day 4. Then Ethanol concentration decreased to about 18 g/L on day 5. The more increasing ethanol led the more decrease of sugar due to the enzyme hydrolysis done by cellulose of the crude enzyme powder during its exponential growth and the decrease of sugar converted to ethanol (Lever et al., 2010; Mamma et al., 1996). In addition, direct energy and material inputs in the ethanol production system are summarized in Table 2, which the GHG emissions per kg of 99.5% ethanol production were calculated. The calculated emission results are presented in Fig.3, representing 123.10 kg CO_2-eq/kg ethanol. The assessment reveals that there were wide ranges of GHG emissions depending on the production environment such as type of fuel used in transportation, water consumption, materials and reagents and electricity used in the ethanol production.

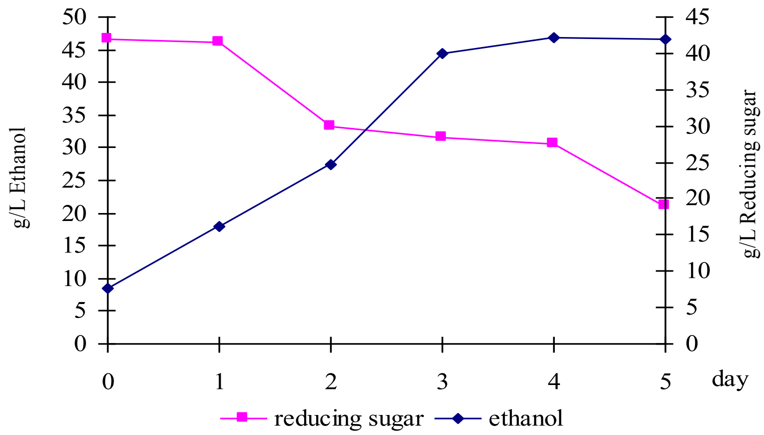

Fig. 2 Ethanol and reducing sugar in batch fermentation (SD 3%)

Table 2 Direct material and energy-related input/output associated with ethanol production system

Segment	Unit	Input	Output
Ethanol conversion			
pineapple peel waste	g	1000.00	
Enzyme	g	750.00	
$CaHPO_4$	g	12.50	
$MgSO_4$	g	12.50	
Urea	g	100.00	
K_2PO_4	g	187.50	
Sugar	g	375.00	
Water	L	12.50	
Electricity	kWh	112.70	
Transportation			
Diesel used for transport	km/L	8.16	
Ethanol product			525.00

The results of this study showed higher ethanol yield than other studies. For example, the maximum yield of bioethanol (9.69g/L) with no hydrogen production by S.cerevisiae with 36 % of cellulose was achieved from pineapple peel after pretreatment with water and heat at 100 0C for 4 h. (Choonut et al., 2014). The fermented broth using S. cerevisiae TISTR 5048 with 20.44 % of cellulose gave the highest percentage of bioethanol yield which was 65 % (Niwaswong et al., 2014). Other studies, lignocellulosic ethanol production could alternatively be done from agricultural wastes such as corn stover, sugarcane bagasse and rice straw (Kadam and McMilland, 2003; Kadam et al., 2000; and Kim and Dale, 2004). Lignocellulosic materials represented a promising option as a feedstock for ethanol production by considering output/input energy ratios, great availability both in tropical and temperate climate countries, low cost (primary related to their transport), and ethanol yields (Sánchez and Cardona, 2008). Furthermore, it was found pineapple peel waste is quite simple, uncomplicated, and low cost as it can be applicable in the ethanol production industries.

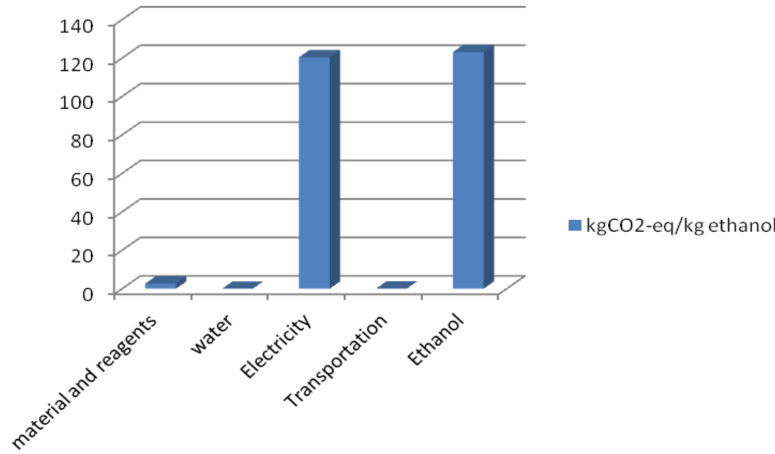

Fig. 3 GHG emissions from ethanol production

In Thailand, with its agriculture-based economy, employs 20% of available agricultural residues through agricultural wastes and by-products. Moreover, there is potential to produce 3.1-8.6 million liters/day of ethanol (Kumar et al., 2013). However, the great production of ethanol from industrial fruit residues can entail serious economic and environmental consequences. The greenhouse gas reduction of ethanol with respect to conventional gasoline, on a well to wheel basis, is about 13% when ethanol is derived from grain; and up to 90% for sugarcane-based ethanol (Quadrelli and Peterson, 2007).

CONCLUSION

The maximum ethanol production was obtained from fermentation crude enzyme powder, which was produced from co-culture of *Trichoderma reesei* RT-P1 and *Saccharomyces cerevisiae* RT-P2. Ethanol values increased on day 4 with the use of 8% dried weight of pineapple peels in 100 mL liquid medium for cultivation at initial pH 5 at room temperature (30^{o}C). Among all processes in the ethanol production system, ethanol conversion created the highest amount of GHG emissions (electricity used), up to 97.8% of the total emissions. Materials and reagents used created 2.1% of the total GHG emissions. The other processes, which were transportation (diesel used) and water consumption created less than 1% of the total GHG emissions. Another encouraging result was 1 kg of non-pretreated pineapple peel waste input could produce 525 g of ethanol fuel, or it is estimated to be 52-53% of ethanol production. In this study, pineapple peel was proved as one of the potential raw materials for bioethanol production. Therefore, agro-industrial fruit residues can be used as feedstock for ethanol production in tropical countries.

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