Greenhouse gas emissions and economic feasibility of ethanol production systems in Thailand

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Abstract Biofuels have received considerable attention as renewable transportation fuels in place of fossil fuels. The Thai government decided to promote the use of bioethanol from molasses and cassava to reduce dependence on imported oil and improve the economic situation of the rural communities. In the present study, we examine ten ethanol plant types classified according to the kind of feedstock used and configuration of ethanol plant and energy source for ethanol production. Life cycle assessment (LCA) has been carried out to determine the greenhouse gas (GHG) emissions from, and the cost of bioethanol production. In the case of Thailand, energy source for heat and power generation and anaerobic wastewater treatment in ethanol plants are key factors for GHG emissions and production cost reduction.

1 Introduction

The Thai government is promoting the production and use of gasohol, which is a mixture of gasoline and ethanol, in order to reduce fossil fuel consumption and to increase energy self-sufficiency. Under the 15-year Alternative Energy Development Plan, which was approved in 2008, The Thai government has the goal of increasing ethanol production to 9.0 million litres per day by 2022. The key driver for this policy is the potential of fuel ethanol to improve the economic condition of farmers and to revitalize the rural economy. Because feedstock crops for fuel ethanol production in Thailand are sugarcane and cassava, which are mainly produced in the Northeast region where GDP per capita is lowest in the country. However, it is suggested that whether bioethanol can offer the greenhouse gas (GHG) benefits depend on how it is produced [1]. If the Thai government continues to promote expansion of ethanol production, it is absolutely essential to evaluate thoroughly the performance of ethanol production and to seek ways to produce ethanol in a sustainable manner.

On the other hand, one major problem with ethanol production in Thailand is economic. The reference price for ethanol trading was so low that it was uneconomic to produce ethanol, especially from cassava. The method of determination for the ethanol reference price was modified, however, the profitability of cassava-based ethanol remains a cause for concern because cassava roots prices keep rising. Meanwhile, molasses prices are also rising sharply in recent years because of strong and rising demand and the economic performance of molasses-based ethanol production tends to deteriorate. Consequently, it is required to improve the economics of fuel ethanol production in order to meet the policy target.

The aim of the present study is to assess the environmental impact and economic feasibility of molasses and cassava ethanol production to identify the most desirable option. Focusing particularly on ethanol production systems, we examine several ethanol plant types. Life cycle assessment (LCA) has been carried out to determine the greenhouse gas emissions from, and the cost of bioethanol production.

2 Materials and methods

2.1 Description of ethanol plant types

In this study, ten ethanol plant types were designed based on the current state of ethanol production system in Thailand in order to evaluate the effects of location of ethanol plant and energy sources for ethanol production. Common assumptions for all ten plant types are as follows: i) plant production capacity is 150 kl of anhydrous ethanol per day, ii) the number of plant operating days per year is 330 days, iii) lifetime of a plant is 20 years. Besides, this study assumes that there would be no technological differences among six plants.

We classify ethanol plants into ten types according to the following criteria: i) kind of feedstock used in the production process; and ii) configuration of ethanol plant and energy source for ethanol production. The ten ethanol plant types evaluated in this study are summarized in Table 1 and each of the plant types is described below.

2.1.1 Feedstock

Ethanol plants are classified into two types by feedstock, i.e., molasses based ethanol plant (ML), and cassava based ethanol plant (CV). This study assumed that feedstock for ethanol production in molasses based ethanol plant is only molasses which is a by-product of sugar production and sugarcane juice is not used as feedstock. Similarly, it was assumed that cassava chips are used for the production of ethanol in cassava based ethanol plant and fresh cassava roots are not used as raw material for ethanol production. Molasses and cassava chips can be stored for long periods and this would allow year round operation of these plants.

2.1.2 Configuration and energy source

Ethanol plants are classified into three types by configuration, i.e., ethanol plant adjacent to existing sugar mill (SG), ethanol plant adjacent to existing tapioca starch factory (TP), and stand-alone ethanol plant (ALN). Sugar mills generate process steam and electricity from bagasse which is the fibrous residue left after crushing sugarcane to extract the juice and sell excess power to the national grid. Therefore, in ethanol plant co-located with sugar mill, all of the steam and electricity needed is provided through combustion of bagasse.

On the other hand, tapioca starch production processes generate a large amount of wastewater with high organic load. In recent years, installation of an anaerobic wastewater treatment system with biogas recovery has been developed in tapioca starch factory and the collected methane gas is utilized as fuel for process steam or power generation. In the ethanol plant co-located with tapioca starch factory, process steam or electricity needed is supplied from the starch factory through combustion of methane gas. A starch factory, however, could not produce sufficient quantities of methane gas to meet all the energy requirements of a starch factory and the co-located ethanol plant. Thus, the remaining steam or electricity requirement is produced by heavy oil.

A huge amount of wastewater with high chemical oxygen demand (COD) concentration is also discharged from ethanol production processes. Many of the newly constructed ethanol plants have installed methane recovery system and the existing plants are in the process of introducing the system using financial mechanisms such as the Clean Development Mechanism (CDM). Consequently, we assumed that in stand-alone plant, the required process steam is obtained through combustion of the methane gas and the needed electricity is purchased from the electric grid.

Tab.1: Classification of ethanol plants

	Feedstock	Configuration	Energy source	
			electricity	process steam
1.ML-SG-bagasse	molasses	co-located with sugar mill	bagasse	bagasse
2.ML-ALN-methane gas	molasses	stand-alone	grid	methane gas
3.ML-ALN-coal	molasses	stand-alone	grid	coal
4.CV-TP-methane gas	cassava	co-located with tapioca starch factory	methane gas	methane gas
5.CV-ALN-methane gas	cassava	stand-alone	grid	methane gas,
6.CV-ALN-coal	cassava	stand-alone	grid	coal
7.M+C-SG-bagasse	molasses cassava	co-located with sugar mill	bagasse	bagasse
8.M+C-TP-methane gas	molasses cassava	co-located with tapioca starch factory	methane gas	methane gas
9.M+C-ALN-methane gas	molasses cassava	stand-alone	grid	methane gas
10.M+C-ALN-coal	molasses cassava	stand-alone	grid	coal

2.2 Functional unit and system boundary

The functional unit for this study is one kl of anhydrous ethanol. We assess the life cycle greenhouse gas (GHG) emissions and costs associated with ethanol production as metrics to compare different plant types. GHG emissions include carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O).

The system boundary includes sugarcane/cassava farming process, transport to a sugar mill/a cassava chip factory, sugarcane/cassava processing process, transport to an ethanol plant, ethanol production process. The mixing process of the ethanol and the gasoline and driving operations by ethanol-fueled vehicles are not included in the system boundary.

The process of sugarcane and cassava farming includes land preparation, planting, fertilizing, weeding and harvesting. In the farming process, the following emissions sources are considered: (i) CO2 emissions due to the use of fossil fuels for farm equipment operation; (ii) N2O emissions from fertilizer application; (iii) CH4 and N2O emissions from sugarcane burning before harvesting; (iv) CO2 emissions due to the use of fossil fuels in the production of fertilizers, herbicides and diesel.

The sugarcane processing process includes several stages such as cutting and shredding, juice extraction, clarification, evaporation, crystallization, centrifugation, carbonation, filtration and decolorization. Cassava processing process includes weighing, chopping and drying. The fuel ethanol production process includes four phases: raw material pretreatment, liquefaction, fermentation, distillation and dehydration. In sugarcane and cassava processing process and ethanol production process, CO2 emissions from energy use are included in the assessment. Energy inputs in the production of chemicals and materials used in each plant are also considered.

In the transportation process, we estimated CO2 emissions from transportation of feedstocks from sugarcane and cassava field to a sugar mill and a cassava chip plant, respectively. Transportation of molasses and cassava chips to ethanol plant is also considered. As for ethanol plant co-located with sugar mill, CO2 emissions from electricity consumption are estimated because molasses are transported through pipeline.

For the economic evaluation of fuel ethanol production, we take into consideration the following three factors: i) initial investment costs, ii) annual operating costs, iii) total revenue. Direct investment costs cover the costs associated with purchasing and installation of equipment and construction of facilities and site development. Indirect investment costs cover the costs associated with engineering and supervision, performance testing, engineering design and contingency. Operating costs can be divided into fixed and variable operating costs. Fixed operating costs include depreciation costs, capital costs, maintenance and repair costs, personnel costs, insurance, and other fixed operating costs. Variable costs include expenses for raw materials, utilities and fuel, and chemicals. These costs are determined by the amount of input required for one unit of output and the purchase price of the input.

3 Results and conclusion

Figure 1 shows the estimation results in each plant type. The bar graph indicates GHG emissions and the line graph indicates production cost. "Reference" represents GHG emissions of gasoline and ethanol reference price. SG type has an advantage in relation to GHG emissions due to the steam and power generation through the combustion of bagasses as energy source. On the other hand, CV type has an advantage in relation to production cost. The plant which located adjacent to the sugar mill and uses molasses and cassava as feedstock can provide an advantage in relation to both GHG emissions and production cost. In the case of Thailand, energy source for heat and power generation and anaerobic wastewater treatment in ethanol plants are key factors for GHG emissions and cost reduction.

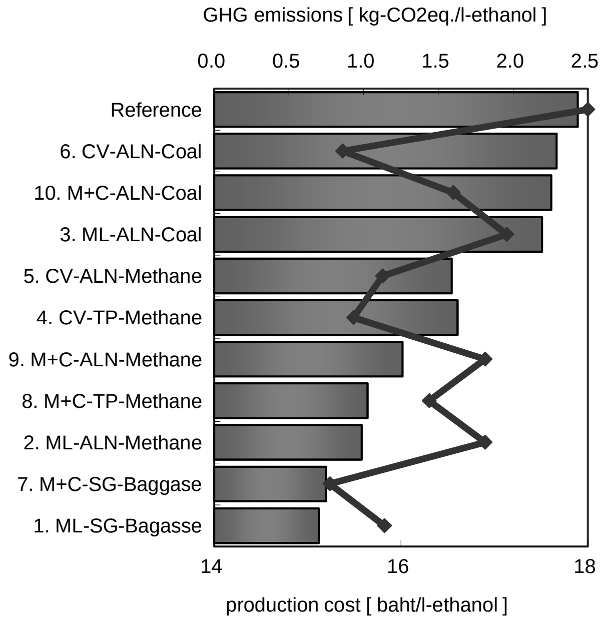

Fig.1: GHG emissions and production cost for each ethanol plant type

4 References

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