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Review

Potential for rice straw ethanol production in the Mekong Delta, Vietnam

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ABSTRACT

This study is to evaluate the potential for development of a cellulosic ethanol facility in Vietnam. Rice straw is abundant in Vietnam and highly concentrated in the Mekong Delta, where about 26 Mt year^{-1} of rice straw has been yearly produced. To minimize the overall production cost (PC) of ethanol from rice straw, it is crucial to choose the optimal facility size. The delivered cost of rice straw varied from 20.5 to 65.4 $ dry t^{-1} depending on transportation distance. The Mekong Delta has much lower rice straw prices compared with other regions in Vietnam because of high density and quantity of rice straw supply. Thus, this region has been considered as the most suitable location for deploying ethanol production in Vietnam. The optimal plant size of ethanol production in the region was estimated up to 200 ML year^{-1}. The improvement in solid concentration of material in the hydrothermal pre-treatment step and using residues for power generation could substantially reduce the PC in Vietnam, where energy costs account for the second largest contribution to the PC, following only enzyme costs. The potential for building larger ethanol plants with low rice straw costs can reduce ethanol production costs in Vietnam. The current estimated production cost for an optimal plant size of 200 ML year^{-1} was 1.19 $ L^{-1}. For the future scenario, considering improvements in pre-treatment, enzyme hydrolysis steps, specific enzyme activity, and applying residues for energy generation, the ethanol production cost could reduce to 0.45 $ L^{-1} for a plant size of 200 ML year^{-1} in Vietnam. These data indicated that the cost-competitiveness of ethanol production could be realized in Vietnam with future improvements in production technologies.

1. Introduction

In the last decade, fast industrialization and the socio-economic development of Vietnam lead to its rapidly growing energy consumption. The country was a net energy exporter during 1990–2010, and currently has been a net energy importer. An increased dependency on fossil fuels is foreseen. The scenario of increasing energy consumption has been anticipated [1]. In which, Vietnam's targets to diversify energy sources, such as nuclear power and renewable energy, increase share of these types of energy in total commercial primary energy and reduce traditional use of biomass energy [2].

Total primary energy consumption in Vietnam has strongly depended on biomass (wood, agricultural residues). Share of biomass energy accounts for more than one third of total energy consumption during the last decade. This non-commercialized energy is traditionally use in rural areas, and 80% of households in rural areas has used biomass for cooking and heating. Traditional use of biomass is ineffective in term of energy and harmful to the environment and human health. Extra amount of waste biomass also creates environmental pollution in some regions with intensively agricultural activities.

Since 2007, several projects have been conducted to produce electricity from biomass, such as rice husks, sugarcane bagasse with

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small to medium scales. Many other types of biomass have not been used. We have seen bioethanol from agricultural residues as an appropriate renewable energy for Vietnam to be developed. As Vietnam has strongly depended on imported gasoline, and this situation is not changed as long as oil refinery industry in Vietnam is incapable. Ethanol is a good additive to gasoline, partially reduces gasoline import and is widely used in transport sector. According to the statistical data of 2010 [3], Vietnamese transport sector accounted for was 22% total energy consumption and produced 16.4% of the country CO_2 emission. Bioethanol production from agricultural residues can significantly reduce gasoline import, CO_2 emission, increase income for farmers, create jobs, and especially provide an environmentally friendly way to deposit biomass in rural areas.

Vietnam is an agriculture-based economy, and rice is the major product. The Mekong Delta region is called 'a rice bowl' and recognized as the most intensively agriculture-activity region of Vietnam, with huge amount of agricultural products and labour force (more than 80% of its population engaging in farming). The intensive agricultural activities in this region demand high energy consumption and create environmental problems related to agricultural wastes [4].

In 2009, Vietnam has cooperated with University of Tokyo to develop the JST (Japan Science Technology)/JICA (Japan International Cooperation Agency) joint project titled “Sustainable Integration of Local Agriculture and Biomass Industries” in 5 years which designate outputs as developing the key technologies for bio-refinery processes including production technologies of bioethanol from lignocellulosic biomass. Within the project, a pilot plant supported by JICA for producing ethanol from rice straw was built in the South of Vietnam for promoting research and developing technologies for cellulosic ethanol production using the abundant biomass supplies from the Mekong Delta area [5]. Nevertheless, to promote cellulosic ethanol production in Vietnam, additional concerns other than conversion technologies should be addressed.

To promote the implementation of bioethanol production from rice straw in the Delta, this research aims to assess the potential of ethanol production from rice straw in this region on the basis of quantity, distribution and farm-plant's gate costs of rice straw, optimum facility's capacity for minimizing the production cost (PC), and PCs at different scenarios via techno-economic analysis.

2. Materials and methods

2.1. Estimation of the rice straw quantity, distribution and available rice straw density for ethanol production

The amount of crop residue generated (dry mass) was estimated on the basis of the data for crop production, residue-to-product ratio (RPR = 1.5), and moisture content (15%) [6]. Density of generated rice straw was calculated by dividing the amount of rice straw for ethanol production in each sub-region by the total area of that sub-region. Rice production by season was used for discussion of rice straw distribution by season.

The available rice straw in an area depends on both field-level and landscape-level factors. Therefore, the available density of rice straw was calculated using the following equation [7,8]:

$$D = Y_s \cdot F_c \cdot F_d \cdot F_p \cdot F_a \cdot 100 \quad (1)$$

where 'D' is the available rice straw density (dry t km^{-2} year^{-1}); 'Y_s' is the rice straw yield (dry t ha^{-1}) (amount of rice straw divided by the rice-planted area); 'F_c' is the collection fraction subject to environmental restrictions; 'F_d' is the rice-planted area density (ratio of rice-planted area to total area); 'F_p' is the proportion of farmers selling the material; and 'F_a' is the accessibility and/or weather inhibiting factors. In Vietnam, there are two or three rice harvest seasons per year, depending on the region. In this study, we assumed that the values of F_c, F_p and F_a were 0.7, 0.8, and 0.3, respectively, for all of the regions.

2.2. Estimation of the delivered rice straw cost in Vietnam

The delivered cost of rice straw was broken down into farmer payments, baling costs, handling costs (e.g., staking on the field edge and loading and unloading the trucks), and transportation costs. Approximately 80–90% of the amount of rice straw generated was disposed of by open-field burning, but, in some periods of the year, rice straw has a market value (in the field) of around 7 USD ($) dry t^{-1} for cattle feed and mushroom cultivation [9]. This price was applied as the cost of farmer payments.

In Vietnam, rice straw is transported in a loose condition. To use rice straw as a feedstock for bioenergy industries, it must be baled to reduce the transportation costs. We applied the baling and handling cost data from Thailand, where the fuel and labour costs are similar to those in Vietnam. The rice straw is baled to achieve a size of 1.2 × 0.4 × 0.5 m (m) − 40 kg for a wet, basic, moisture content of 11%. The baling cost and handling costs were $9 t^{-1} and $4.5 t^{-1}, respectively [10]. The transportation costs depend on such variables as the transportation distance, feedstock moisture, bale density, and road quality. The technical standard for design of rural roads on connecting rural district-commune-village-hamlet-fields in Vietnam was referred [11], such as road width, weight and speed limit of vehicles for transportation, etc. as well as the opinions from experts in transportation sector to assume the type of truck that can be applicable for delivering rice straw from fields to the facility's gate. As such, we assumed that each truck has a volume capacity of 78 m^3 and a loading weight of 6 tons, for the transport of feedstock to an ethanol facility at a cost of $2 km^{-1} [12]. As mentioned above, the rice straw bale density was 40 kg bale^{-1} (0.24 m^3), for a wet, basic, moisture content of 11%. Thus, this type of truck can carry 150 bales with the weight of 6 tons, volume of 36 m^3. Therefore, the hauling cost per-unit weight–distance (Hc) was given by the following equation:

$$Hc = 2\left(\$\,\mathrm{km}^{-1}\right)\Big/\left[6\left(\mathrm{ton}\right)\times\left(1-0.11\right)\right] = \$0.375\,\mathrm{dry}\,t^{-1}\,\mathrm{km}^{-1} \quad (2)$$

Average feedstock transportation cost per dry ton of feedstock and the per-unit feedstock transportation cost.

In calculating the transportation cost of the feedstock, a simple model was applied that assumed a circular collection area, with a facility at the centre; no discrete farm locations were considered, and it was assumed that the farmland was uniformly distributed. The average transportation distance from fields to the facility gate was given by the following [13,14]:

$$\text{Average transportation distance} = 2/3 \cdot \mathrm{R} \cdot \tau\ (\mathrm{km}) \quad (3)$$

where R is the radius of the collection area (km); and τ is the tortuosity factor (ratio of the actual distance travelled in a straight-line distance). The tortuosity factor can be as low as 1.27 for developed agricultural regions, where the area is laid out in a rectangular grid over a flat terrain, and as high as 3.0 for poorly developed regions [14]. In the present study, we assumed $\tau = 1.5$ for a base case. Thus, the per-unit feedstock transportation cost was given by the following:

$$\text{Per}-\text{unit transportation cost}\left(\$\mathrm{L}^{-1}\right) = 2/3 \cdot R \cdot \tau \cdot Hc/Y \quad (4)$$