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Potential of Ethanol Production from Major Agricultural Residues in Southeast Asia

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Abstract – *Much attention has been paid to fuel ethanol recently, for gasoline substitution and alleviation of global warming. However, the use of food resources for fuel ethanol is controversial and the use of non-food resources is anticipated. Ethanol production technology based on milling pretreatment and enzymatic hydrolysis was developed. We estimated ethanol production potential from three major agricultural residues, rice straw, sugarcane bagasse, and empty fruit bunches (EFB) from oil palm, for six Southeast Asian countries. Our estimation for maximum possible ethanol production potential based on experimental data showed that more than 40% of gasoline consumption can be substituted by ethanol produced from those residues, as the sum of six countries. Further increase of ethanol production can be expected with improvement of hydrolysis rate, xylose utilization, or use of other residues. Southeast Asian countries have large ethanol production potential without utilizing food resources.*

Keywords – Bagasse, empty fruit bunch, fuel ethanol, rice straw, Southeast Asia.

1. INTRODUCTION

The production and use of fuel ethanol as a substitute for gasoline has been highly concerned recently. The current oil price rise is a certain reason for it, but the use of fuel ethanol is also effective to alleviate the global warming. While the United States and Brazil are the two major producers and consumers of fuel ethanol, more than 40 countries worldwide have shown interest on fuel ethanol [1].

Asian countries are rich in agricultural products, and the use of fuel ethanol produced from domestic resources is effective for reducing petroleum consumption and improve their balance of trade. In Asian area, the present major materials for fuel ethanol are the sugarcane molasses, or starch from cassava or corn. The utilization of those products as feedstock is also beneficial for the agricultural sector. However, the production of biofuels from such resources is controversial, because it is considered to be one of the major factors for the current upsurge of food prices. Although Asian countries have large agricultural production potential in general, their large population and rapidly growing economy can boost fuel ethanol demand, and procuring feedstock with reasonable prices might be difficult even in Asian countries. Hence, the technology to produce ethanol from non-food feedstock like agricultural residues is anticipated.

Agricultural residues, such as rice straw, or sugarcane bagasse, consist of three major components; cellulose, hemicellulose, and lignin. Cellulose, the major component, is crystalline and very rigid. Hence, development of efficient hydrolysis technology for cellulose is the most important research issue for ethanol production from those lignocellulosic biomass. Lignin and hemicellulose fill in the gaps between the cellulose molecules and protect cellulose from microbial attack. For enzymatic hydrolysis, appropriate pretreatment is essential to break this protection and make enzymes more accessible to cellulose. The research for ethanol production from woody biomass with milling pretreatment and enzymatic hydrolysis was conducted [2], which also can be applied to agricultural residues. This technology is advantageous in high sugar yields, small requirement of enzyme, and little formation of fermentation inhibitory substances.

There are several reports for estimations of biomass potential in the world [3], [4] or in Asia [5]–[7], however, they deal with the potential of raw biomass resources and not for amounts of possible ethanol production. Although a study for ethanol production potential from wasted crops and crop residues was reported [8], it was based on theoretical ethanol yields including xylose utilization and showed potential only for whole Asia.

Several Japanese research organizations implemented a research project, "ASEAN Biomass R and D Strategy" in order to address the strategy for efficient utilization of biomass resources in ASEAN countries [9]. We report here the estimations of ethanol production potential from three major agricultural residues in six ASEAN countries, based on experimental data with the milling and enzymatic hydrolysis technology.

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2. EXPERIMENTS

Sugar recovery experiments for rice straw and bagasse were conducted with milling and enzymatic hydrolysis procedure. Milling pretreatment for bagasse and rice straw was performed with a planetary ball mill (Pulverisette 7, Fritrsch, Germany), using 1.0 g of each sample in a 45-ml milling cup. Milling was carried out with 12 cycles of 10-min milling at 400 rpm and 10-min rest.

Enzymatic hydrolysis was carried out with the commercial enzyme mixture which consists of cellulase (Acremonium cellulase, Meiji Seika, 4 or 40 FPU/g substrate), beta-glucosidase (Novozymes 188, 5 U/ml), and 2% (v/v) of hemicellulase (Optimash BG, Genencor), in 50 mM Na-acetate buffer at 45˚C for 72 h. The major enzyme was Acremonium cellulase, which is produced with a fungus isolated in Japan [10]. Filter Paper Unit (FPU) is a general indicator of total cellulase activity recommended by International Union of Pure and Applied Chemistry (IUPAC) based on the hydrolysis of filter papers [11]. Hydrolysis was implemented with either high (40 FPU/g substrate) or low (4 FPU/g substrate) dosages of cellulase. Optimash BG has high xylanase and beta-xylosidase activities which is suitable for the hemicellulose hydrolysis of herbaceous materials.

The concentrations of sugars and ethanol were determined by HPLC using Aminex HPX-87P column (7.8 mm I.D. X 30cm, BioRad) and a refractive index detector (RI-2031Plus, JASCO). The mobile phase was doubly-deionized water, and the flow rate was 1.0 ml min^{-1} with the column temperature of 80˚C.The contents of glucose and xylose in materials were determined after complete acid hydrolysis and sugar analyses by HPLC. Sugar yields were calculated on the basis of sugar contents obtained by acid hydrolysis.

3. METHODOLOGY FOR ESTIMATIONS

In "ASEAN Biomass R and D Strategy" project, three most promising agricultural residues in ASEAN countries are identified: rice straw, sugarcane bagasse, and oil palm residues [9]. Accordingly, we focus on those resources for possible feedstock for ethanol production in this study. Among oil palm residues, empty fruit bunch (EFB) is the most abundant cellulosic resource [12], and easily available at oil mills. Hence, we concentrate on EFB for oil palm residues. We selected six ASEAN countries (Vietnam, Thailand, Myanmar, Malaysia, Indonesia, and the Philippines) as objects for analyses. We did not study for other ASEAN countries, Laos, Cambodia, Singapore, and Brunei, because their agricultural production is much smaller. The data of rice and sugarcane production in 2006 were obtained from FAO statistics (FAOSTAT) [13]. The amounts of crude palm oil production in 2006 were obtained from Indonesian Palm Oil Association [14].

For the estimation of resource amounts, residue product ratios were determined based on data in literatures.

Rice straw (dry wt.) / paddy rice (dry wt.) = 1.5 [15].

Bagasse (dry wt.) / sugarcane (fresh wt.) = 0.15 [15].

EFB (dry wt.) / crude palm oil = 0.4 [16]

Straw to grain ratios of rice vary largely depending on varieties or cultivation conditions [17]. The data in the literature [15] considering water content of straw was adopted. For actual calculation, the 25% moisture content of rough rice [18] was assumed.

Contents of glucose and xylose are obtained by the complete acid hydrolysis experiments. Enzymatic hydrolysis rates were determined with ball-milling and enzymatic hydrolysis procedure. Since technologies for glucose fermentation and purification of produced ethanol are common to conventional ethanol production from sugars or starch, the fermentation and process recovery efficiencies of 0.85, and 0.9, respectively were fixed for all materials.

Ethanol yield (Y) was calculated with the following equation.

Y (L) = Amounts of resources (kg) x H x F x P x 0.51 / 0.79 (kg/L).

H is the sugar recovery from glucan hydrolysis, F is the fermentation efficiency, and P is the process recovery efficiency. The theoretical ethanol yield from sugars is 0.51 and 0.79 is the specific gravity of ethanol. Since xylose utilization as substrate for ethanol fermentation is not well-established in terms of practical production at the present time [19], [20], the ethanol production from xylose was not considered.

The data of gasoline consumption in 2006 were obtained from IEA Energy Statistics [21].

4. RESULTS AND DISCUSSIONS

Glucose and xylose contents and sugar recoveries after milling and enzymatic hydrolysis of materials are shown in Table1.

Table 1. Sugar contents and hydrolysis rates for three kinds of agricultural residues.

	Content (g/dry g)	Hydrolysis rates (%)	
		4 FPU	40 FPU
Glucose			
Rice Straw	0.289	88.2	91.7
Bagasse	0.404	84.8	91.7
EFB	0.417	38.7	44.2
Xylose			
Rice Straw	0.148	70.1	78.3
Bagasse	0.207	74.2	84.0
EFB	0.251	43.2	43.8

The values for EFB were from the data determined with the same procedure [22]. For enzymatic hydrolysis, the higher cellulase dosage (40 FPU/g substrate) naturally gave higher sugar yields, but the differences between lower dosage (4 FPU/ g substrate) experiments are relatively small in all materials. The sugar recovery from the lower dosage experiments for the analyses was used, considering the high cellulase costs [23]. One advantage of milling pretreatment is high hydrolysis rate even at lower cellulase dosage [2].

Table 2 shows the estimated ethanol production potential from rice straw in six ASEAN countries. Since rice is the major crop in most ASEAN countries, potential from rice straw is quite large, except for Malaysia.

Table 3 shows the estimated ethanol production potential from sugarcane bagasse. Thailand is the largest producer of sugarcane in ASEAN, and has large ethanol production potential from bagasse.

Table 4 shows the estimated ethanol production potential from EFB. Indonesia and Malaysia are the two major oil palm producers in the world and have large ethanol production potential from EFB. Little oil palm production is reported for Vietnam, Myanmar, and the Philippines. Although coconut palm is widely cultivated in the Philippines, we did not consider coconut wastes in this study, because their properties are different from those of oil palm.

Table 2. Ethanol production potential from rice straw in Southeast Asian countries.

Country	Rice Production (10^9kg)	Straw Amount (10^9kg)	Ethanol Production (10^9L)
Vietnam	35.8	40.3	5.09
Thailand	29.3	32.9	4.15
Myanmar	30.6	34.4	4.34
Malaysia	2.2	2.4	0.31
Indonesia	54.5	61.3	7.73
Philippines	15.3	17.2	2.18
Total	167.7	188.5	23.80

Table 3. Ethanol production potential from sugarcane bagasse in Southeast Asian countries.

Country	Sugarcane Production (10^9kg)	Bagasse Amount (10^9kg)	Ethanol Production (10^9L)
Vietnam	15.7	2.4	0.40
Thailand	47.7	7.1	1.21
Myanmar	7.3	1.1	0.19
Malaysia	0.8	0.1	0.02
Indonesia	25.2	3.8	0.64
Philippines	24.4	3.7	0.62
Total	121.1	18.2	3.09

Table 4. Ethanol production potential from oil-palm EFB in Southeast Asian countries.

Country	Palm oil Production (10^9kg)	EFB Amount (10^9kg)	Ethanol Production (10^9L)
Thailand	0.9	0.34	0.03
Malaysia	15.9	6.35	0.51
Indonesia	16.1	6.42	0.51
Total	32.9	13.1	1.05

Figure 1 shows the total ethanol production potential from three kinds of agricultural residues in six ASEAN countries. In Indonesia, nearly 9 billion litres of ethanol can be produced from the residues, and about 5 billion litres for Vietnam, Thailand, and Myanmar, and 3 billions for the Philippines, respectively. In Malaysia, potential is smaller because of relatively small rice and sugarcane production, and about 60% of ethanol can be produced from EFB. In other five countries, potential from rice straw accounts for more than 75%.

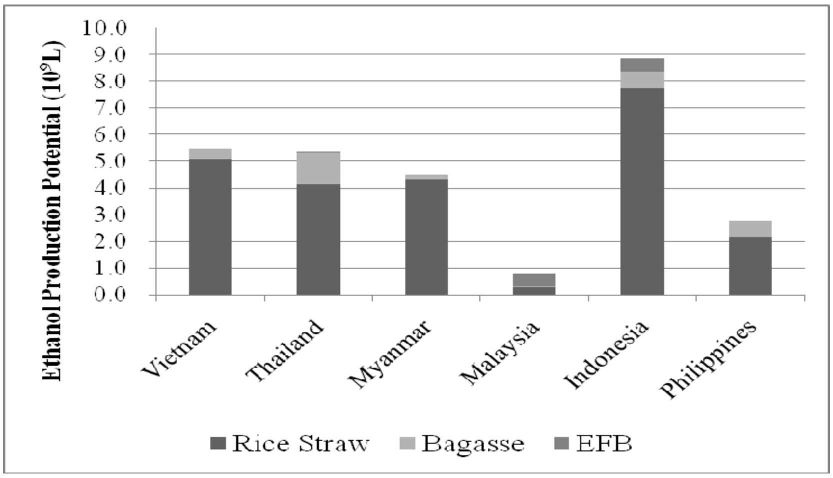

Fig. 1 Ethanol production potential from three major agricultural residues in Southeast Asian countries

Table 5. Gasoline substitution potential with ethanol from agricultural residues in Southeast Asian countries.

Country	Gasoline consumption (PJ)	Possible gasoline substitution (Energy basis)	
		PJ	%
Vietnam	122	116.0	94.8
Thailand	235	114.1	48.5
Myanmar	16	95.8	602.9
Malaysia	348	17.6	5.1
Indonesia	574	187.8	32.7
Philippines	116	59.1	50.8
Total	1411	590.3	41.8

Table 5 shows the substitution potential for gasoline consumption on the energy basis with ethanol from three kinds of agricultural residues.

Ethanol production potential is quite large. If all of the residues were used for ethanol, almost all the gasoline consumption can be covered in Vietnam, and about 30–50% can be substituted in Thailand, Indonesia, and the Philippines. The substitution rate is much smaller in Malaysia, because of small production of rice and sugarcane along with large gasoline demand. Myanmar is considered to be a special case because its gasoline consumption is very small. As the sum of six countries, more than 40% of gasoline consumption can be substituted.

We showed the maximum possible potential from the estimated amounts of resources. However, it is impossible to utilize all the resources for the feedstock of ethanol. Bagasse is efficiently utilized as fuel to produce steam or electricity in sugar mills. For rice straw, some portions are utilized as animal feed, fertilizer, or fuel by direct combustion. Although plowing straw into the fields is one measure for disposal, it returns nutrients to the fields and benefits the soil condition. On the other hand, burning of straw is not only an environmental concern, but also suggests a surplus. The amount of field-burned rice straw is estimated to be 48% of the total straw in Thailand and 95% in the Philippines [24]. These values can be indicators for excess straw amounts available for ethanol, but situations vary among countries and we cannot set a general index.

Although Kim and Dale [8] already reported global bioethanol production potential from several kinds of crop residues, the potential by our estimations should give smaller amounts from the following reasons.

(1) Our estimations are based on the hydrolysis rate obtained from actual experiments with the low enzyme dosage along with modest values for fermentation and process recoveries, while Kim and Dale used theoretical yields.

(2) Our estimations are based on only production from glucose obtained by hydrolysis of cellulose. As mentioned before, we excluded xylose as fermentation feedstock in this study.

Although our estimations can be moderate ones, there is the problem of resource availability mentioned above.

In addition to our estimation, there are several factors which can boost ethanol production potential:

(1) Development of technology for more efficient hydrolysis and fermentation.

For EFB, hydrolysis rate was much lower than those for rice straw or bagasse (Table 1). We do not know the reason at the present time. The EFB sample we used was totally dried and very rigid. However, oil palm fresh fruit bunches (FFB) are steam sterilized in oil mills to inactivate lipase, and this could be considered as pretreatment. Hydrolysis rate might be improved if we use EFB right after the treatment at oil mills. If we can obtain the same hydrolysis rate for rice straw or bagasse, ethanol production from EFB will be doubled.

(2) Agricultural residues contains xylose and its content is about half of glucose (Table 1). If we can utilize xylose in practical production, additional amount of ethanol will be obtained. Fulfillment of practical xylose utilization depends on development of microorganisms that can efficiently convert xylose into ethanol. Many laboratories in the world are conducting the research [25]. Recently, new yeast strain that can ferment xylose more efficiently was reported [26].

(3) There are other residues which were not considered here. The amount of rice husk is estimated about 20-25% of rice straw [27]. Rice husk is more advantageous than straw in terms of collection. The amount of sugarcane agriculture residues, like top and leaves, is reported to be equivalent to bagasse [16], while they are not highly utilized as bagasse. Palm press fiber is obtained about 14-15% of FFB [28], or about two-third amount of EFB. We did not estimate ethanol production potential from those resources, because we did not have experimental data for them. But we believe we can utilize them with our technology for hydrolysis, because they are all lignocellulosic biomass.

5. CONCLUSION

Our estimations of ethanol production potential from three kinds of major agricultural residues showed that they are quite large in Southeast Asian countries. Several billons of ethanol can be produced from the residues in each country except for Malaysia. Malaysia has much smaller potential and is unique for its high dependence on EFB. Quite amounts of consumed gasoline can be substituted by the ethanol from the residues in each country. As the sum of six countries, more than 40% of gasoline consumption can be substituted. Further increase in ethanol production from agricultural residues can be expected with improvement of hydrolysis rate, xylose utilization, or use of other residues. Southeast Asian countries have large ethanol production potential without utilizing food resources.

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