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Potential of Bioethanol Production from Agricultural Residues in the Mekong Delta, Vietnam

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Abstract *– The potential of bioethanol production from agriculture residues in the Mekong Delta, Vietnam, on the basis of the available quantity and distribution of residues was assessed. The results showed that rice straw (28.67MT year^{-1}) accounted for 79% of the total agricultural residues generated in the Delta. Considering the collection efficiency and other uses of rice straw, we assumed that 50% of the rice straw generated annually could be used for sustainable ethanol production. Analysis of rice-straw distribution by season and sub-region in the Delta showed the great potential of this feedstock supply for bioethanol plants. The quantity of rice straw was abundant, provided mainly from the spring and autumn rice harvest seasons. The areas with a high density of rice straw supply were located along the upper and mid-banks of the Tien and Hau Rivers. The ethanol production potential from rice straw in the Mekong Delta could be 1837 ML year^{-1} or up to 3645 ML year^{-1} (without or with xylose fermentation) when using the existing rice-straw ethanol production technologies developed in Japan. These amounts of ethanol could substitute for 28.4% to 56.4% of the total gasoline consumption in Vietnam, as estimated on the basis of 2008 figures.*

Keywords – Agricultural residue, bioethanol, feedstock, rice straw and xylose.

1. INTRODUCTION

Increased concerns for the security of the oil supply and the negative impact of fossil fuels on the environment, particularly greenhouse gas emissions, have put pressure on most nations in the world to develop renewable energy (*e.g.*, solar, wind, or biomass). Among the various types of bioenergy sources, biofuels offer specific advantages, since they are infinitely available and compatible with current transportation infrastructure. The production cost of biofuels steadily decreases with the technological development in conversion processes and feedstock production. With these advantages, biofuels are emerging as promising options with which to cope with climate change and the diminishing oil supply [1].

Biofuel production has increased rapidly over the last decade. Bioethanol accounts for approximately 75% of the total biofuel produced globally (68 billion liters in 2008) [2]. While Brazil and the United States are currently the two major producers and consumers of bioethanol, more than 40 other countries have shown interest in this ethanolic fuel [3]. To date, the most widely used feedstock materials for bioethanol are sugarcane (Brazil), maize (USA), sugar beet, cassava, and so forth. The rapid increase in the production of ethanol from those food crops has been criticized as a threat to food security. Therefore, lignocellulosic biomass resources such as rice straw, maize stalk, and wood are expected to be used widely as substitute feedstock for the sustainable production of bioethanol, without the food supply competition [4].

Vietnam's primary energy demand is projected to grow at an annual rate of 4.4%, from 42 million tons of oil equivalent (Mtoe) to 142 Mtoe in 2030, as a result of the industrialization of the economy. Vietnam is anticipated to become a net energy-importing country beyond 2020 [5]. To assure energy security and environmental protection, Vietnam's government approved a scheme in 2007 for the development of biofuels until 2015, with a vision to 2025; the target is to produce 1.8 million tons of ethanol and vegetable oil per year by 2015 to satisfy approximately 5% of the country's total gasoline demand [6]. The energy supply in Vietnam still heavily depends on biomass energy (forest residues, agricultural residues, *etc.*), which accounted for nearly 45% of the total primary energy supply in 2007 [7]. Even worse is that these resources are still primarily used in the traditional way which causes environmental pollution with low energy efficiency. This biomass resource should be exploited to produce biofuels for energy security and environmental conservation as well as social economic development.

Vietnam is very rich in lignocellulosic biomass. The economy produced about 92 million tons (MT) of crop and forest residues in 2002, which could be converted to 28 Mm^3 of ethanol or 13 MT of gasoline equivalent. This volume is more than enough to displace the current gasoline consumption [8]. According to one report, the total rice straw and sugarcane bagasse generated in Vietnam could be used to produce around

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5,090 million liters (ML) of ethanol [9]. Other reports have demonstrated the great potential of lignocellulosic biomass in Vietnam for the production of fuel or energy [10]–[12]. These reports assumed that all generated residues are available for bioenergy and biofuel production, and would result in a maximum potential for the entire country. In practice, not all generated residues can be used for biofuel production because of scattered abundance and diversion to other uses (*e.g.*, animal fodder, fertilizer, and domestic heating and cooking). To date, no detailed analyses of biomass resources (by province or municipality) have been identified.

This study focuses on the Mekong Delta region in the southern part of Vietnam, which covers 12% of the total area of the country. The intensive agricultural activities in this region demand high energy consumption and create environmental problems related to agricultural wastes [13]. This research aims to assess the potential of ethanol production from agriculture residues in this region on the basis of availability, sub-region, and seasonal distribution of such residues, and practically estimate ethanol production potential. In addition, this study can contribute to the effective planning and implementation of rural energy intervention programs in the Mekong Delta.

2. AGRICULTURAL PRODUCTION AND BIOMASS UTILIZATION IN THE MEKONG DELTA

The Mekong Delta is one of six administrative units of Vietnam, located in the southern tip of the country, where the Mekong River approaches and empties into the sea through a network of distributaries. Thus, the Delta is endowed with important natural resources: fertile soil and water. This region covers an area of 40,602 km^2, 64% of which is used for agricultural production and aquaculture. The population of the region is around 17 million, 80% of whom are engaged in agricultural production [14].

The comparison of the annual crop production in the Delta with that of the entire country is shown in Table 1. Rice produced in this region accounts for nearly 60% of the total Vietnamese rice output and is more than that produced in other countries such as the Philippines (15.97 MT) or Japan (10 MT) [15], [16]. The Delta possesses a favorable equatorial climate for agricultural production, especially for rice cultivation. About 1.7 million ha of the region are under rice cultivation, and most of this area uses the triple rice crop system. Therefore, the total rice-planted area in the Mekong Delta is 3.859 million ha—more than 50% of the rice-growing area in Vietnam, with an average yield of more than 5 tons ha^{-1}. This region is also famous for sugarcane production and accounts for one third of the total annual sugarcane output in Vietnam.

In addition to annual crops, perennial crops such as coconut are strengths of the Delta: 60% of the 1.086 million ha planted in coconut in Vietnam is located in this region. Annually, around 3 MT of coconut residues are generated, and mostly exploited for producing handicrafts, exported fibers, charcoal, growing materials, *etc.* [10]. However, the most abundant source of biomass in the Delta is mainly from rice cultivation [17]. Rice husks and sugarcane bagasse have been the main agricultural residues used for energy supply in the Delta. Approximately 80% of the bagasse generated is used for the production of electricity, heat, and steam in sugar plants and small sugar mills [18]. Rice husks are used as the main energy source in brick kilns, homemade alcohol production, rice dryers, and power co-generation plants. It was reported that the electricity and heat energy obtained from rice-husk burning in furnaces, kilns, or stoves are in high demand by the Mekong Delta's rural industries, in both the present and for the future [17]. Currently, rice straw and other agricultural wastes are not popularly used for energy supply and have been dumped into rivers or burnt openly in the fields, causing environmental problems in the region. Thus, technologies to convert agricultural wastes into energy have been promoted to satisfy the energy demands within the community of the Delta and conserve the environment [13].

Table 1. Annual crop production in Vietnam and the Mekong Delta in 2008 [20].

	Planted area (10^6 ha)		Production (10^6 ton)	
	Whole country	Mekong Delta	Whole country	Mekong Delta
Rice	7.414	3.859	38.725	20.682
Maize	1.126	0.041	4.531	0.230
Sweet potato	0.162	0.013	1.324	0.242
Cassava	0.558	0.007	9.396	0.107
Sugarcane	0.271	0.065	16.128	5.084
Groundnut	0.256	0.014	0.534	0.043
Soya-bean	0.192	0.007	0.269	0.016

3. AGRICULTURAL RESIDUES IN THE MEKONG DELTA

3.1 Agriculture Residue Generation

Table 2 shows the quantity of residue generated annually. The amount of crop residue generated (dry mass) was estimated on the basis of the data for crop production, residue ratio, and moisture content. The residue ratio is a crop-specific estimator which, when multiplied by the crop yield, identifies the actual amount of residue produced by a unit of harvested crop [19].

There were no substantial changes in crop-planted areas in last several years. The data used for the calculation of agricultural residue quantity are based on the average value of crop production over five years (2004–2008) obtained from the Statistical Yearbook of Vietnam 2008 [20]. The values for the crop residue ratio and moisture content varied with crop varieties, cultivation conditions, and harvesting methods. This study applied the values used for the estimation of crop-residue production in Asian countries [15], [21].

Residues generated from rice cultivation account for 92.4% of the total residues, and represent the major part of the total agricultural residues in the Mekong Delta. This rice cultivation residue comprises rice straw and rice husks at levels of 28.67 MT (79%), and 4.87 MT (13.4%), respectively. This rice straw quantity is more than double that in the case of Japan (9.6 MT), and almost the same as that for Thailand (32.9 MT) and Myanmar (34.4 MT) [9], [15]. The huge amount of rice straw generated in the 4 million ha area indicates that the density of rice straw is higher in this region than in the other regions and countries. After rice, sugarcane contributed a quite large amount of residue. The quantities of sugarcane tops/leaves and bagasse annually generated are 1.32 MT (3.64%) and 0.71 MT (1.96%), respectively. Other crops produce much smaller quantities of residues than do these main crops (rice and sugarcane); thus, these minor residues can be neglected for their contribution to the agricultural residues total.

Table 2. Annual agricultural residue generation in the Mekong Delta.

	Production (10^3 ton year^{-1})	Residue	Residue ratio	Moisture content (%)	Residue generation (dry 10^3 ton year^{-1})
Rice	18693.0	Straw	1.757	12.71	28,670
		Husk	0.267	2.37	4,873
Maize	172.7	Stalk	2.0	15	294
		Cob	0.273	7.53	44
		Husk	0.2	11.11	31
Sweet potato	228.8	Stalk	1.14	11	232
Cassava	71.1	Stalk	0.2	25	11
		Peeling	0.03	50	1
Sugarcane	4896.5	Bagasse	0.29	50	710
		Tops/leaves	0.3	10	1,322
Groundnut	36.0	Husk	0.477	8.2	16
		Straw	2.3	15	70
Soybean	10.5	Straw	2.5	15	22
		Pod	1.0	15	9
Total					36,303

3.2 Availability and Distribution of Rice Straw

As mentioned above, rice husks and bagasse mostly have been used for heat, steam, and electricity generation in rural industries and other power cogeneration plants in the Delta. Considering its abundant supply as well as its suitable composition for ethanol production, rice straw will be a potential feedstock for ethanol production in the region.

In the Mekong Delta, most of rice straw generated has been either plowed in or burned directly on the field. It was stated that more than 87% of the generated rice straw is burned on fields [22]. Some rice fields have no rice straw collected, especially in the winter rice season.

Another paper reported that only 10% of the collected rice straw is used for the feeding and bedding of cattle or buffaloes, mushroom cultivation, composting, while the remaining 90% is used for energy supply [17]. Even though burning adds a considerable amount of ash to the soil and improves its fertility, it harms the environment. Thus, large amounts of generated rice straw should be collected in part for ethanol production. Considering the possibility of collection and other uses, it was assumed that 50% of the rice straw generated each year could be used for sustainable ethanol production.

The data used for the calculation of annually generated rice straw are based on the average value of rice production over five years (2004–2008) obtained from the Statistical Yearbook of Vietnam 2008. Rice production in the Delta has increased in recent years, but will be reduced because of an urbanization rate of 2.5% per year and thus, the reduction of agricultural land [17].

Fig. 1. Sub-regions in the Mekong Delta, Vietnam [23].

Table 3. Annual rice straw availability for ethanol production in the Mekong Delta by sub-region.

	Area (10^3 ha)	Rice straw (dry 10^3 ton year^{-1})		
		Generation	Availability	Share (%)
Long An	449.4	2,870	1,435	9.84
Tien Giang	248.4	1,976	988	6.78
Ben Tre	236	526	263	1.80
Tra Vinh	229.5	1,536	768	5.27
Vinh Long	147.9	1,405	702	4.82
Dong Thap	337.5	3,711	1,855	12.72
An Giang	353.7	4,560	2,280	15.64
Kien Giang	634.6	4,348	2,174	14.91
Can Tho	140.2	1,984	992	6.80
Hau Giang	160.1	1,569	784	5.38
Soc Trang	331.2	2,339	1,169	8.02
Bac lieu	258.5	1,096	548	3.76
Ca Mau	533.2	751	375	2.57
Total (Mekong Delta)	4060.2	28,670	14,335	100.00

The amounts of rice straw could be used annually for ethanol production in the Delta and its sub-regions are shown in Table 3. The total amount of available rice straw for ethanol production in the Delta is around 14.335 MT year^{-1}; this amount is even greater than the total rice straw generated each year in other countries such as Korea and Japan [1], [15]. The Mekong Delta region is divided into 12 provinces and one municipality (Can Tho)—or 13 sub-regions (Figure 1). The available amount of rice straw is different in each sub-region. An Giang, Kien Giang, Dong Thap, and Long An have more rice straw than do the other sub-regions, and they account for 15.6%, 14.9%, 12.7%, and 9.8% of the total rice straw in the Delta, respectively. The quantity of available rice straw in An Giang alone is 2.28 MT year^{-1}, almost the same as the total rice straw generated in Malaysia (2.2 MT year^{-1}) [9].

To consider the high potential of rice straw as a feedstock supply for ethanol production, assessment of the rice straw density by location (sub-region) and season is essential for the proper planning of activities that precede actual utilization. Such activities include locating ethanol plant building sites, as well as collection, transport, and storage.

The distribution of the available rice straw is represented by the sub-regional rice straw densities (mass/area/year, Figure 2). Rice straw is available in high density in Can Tho, An Giang, Dong Thap, Hau Giang, Vinh Long, and Tien Giang, ranging from approx. 4 to 7 tons ha^{-1} year^{-1}. Because these sub-regions have high percentages of land use and good soil for rice cultivation, rice yields are more than 6 tons ha^{-1} [20]. However, the contribution of rice straw amounts from each sub-region varies because of the disparity in their total areas. Can Tho is the municipality in the Delta, with the highest density of rice straw available for ethanol production (7 tons ha^{-1} year^{-1}), but it has a lower amount of rice straw than do other sub-regions. An Giang could be considered as the best site in terms of the total amount as well as the high density of rice straw for ethanol production.

In summary, large rice-planted areas with high potential for rice straw collection are located along the upper and mid-banks of the two main rivers, the Tien River and the Hau River (see the circled areas in Figure 1). These areas belong to sub-regions: An Giang, Can Tho, Hau Giang, Kien Giang, Dong Thap, Vinh Long, Long An, and Tien Giang. These sub-regions have fertile soil and water from the rivers and are less affected by seawater intrusion due to high tides, floods, and inundation. The annual flooding season in the Mekong Delta lasts for five months, between July and November, primarily in the lower parts of the Delta [24].

There are three rice seasons in the Mekong Delta: winter, autumn, and spring. The seasonal distribution of rice straw is shown via rice production by season (Figure 3). The winter, autumn, and spring rice seasons represent about 7%, 45%, and 48%, respectively, of the total annual rice output in the Delta. Winter rice season starts in the rainy season, in July or August, and ends at the close of the rainy season in November or December. Local rice varieties with low yields (4 tons ha^{-1}) that are adapted to deep water are grown in this season. The spring rice season starts at the end of rainy season (November–December) and yields the first harvest in February or March. The autumn rice season starts in May or June and is harvested in mid-August or September. Rice straw generated in the winter season accounts for just 7% of the total supply and is less efficiently collected because of deep water. The rice straw supply is mainly from the rice harvest seasons of spring and autumn, particularly from February to September [14], [25]. Thus, rice straw generated during this time could be collected for ethanol production and other uses. Two main rice-straw-supply seasons per year are considered advantageous because fewer storage yards would be required to ensure a constant supply of feedstock throughout the year, as compared to other countries that have one rice season per year.

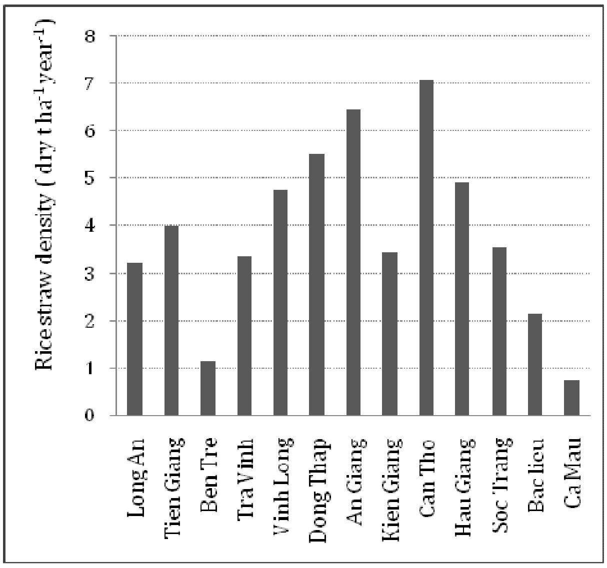

Fig. 2. Density of available rice straw for ethanol production by sub-region.

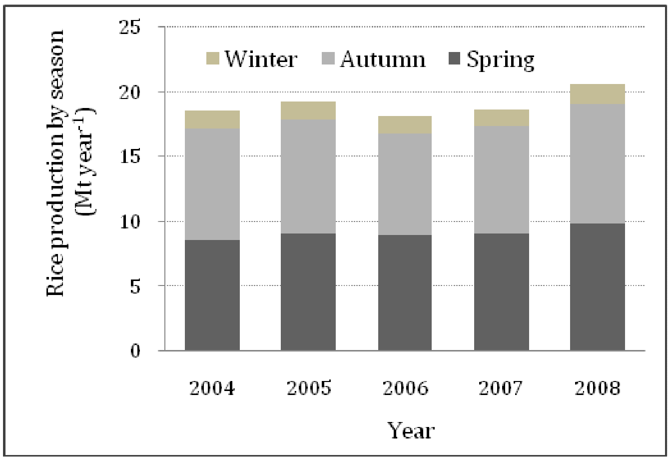

Fig. 3. Rice production by season in the Mekong Delta [20].

4. ESTIMATION OF ETHANOL PRODUCTION FROM RICE STRAW

The amount of ethanol that can be produced from a dry ton of residue will depend on the composition of the crop residues and the ethanol production methods. In this study, the rice-straw ethanol yields based on the experimental or 60%-of-theoretical yield data was used:

- By experimental studies performed at the Biomass Technology Research Center, AIST Chugoku, Japan, the experimental rice-straw ethanol yield was determined to be 0.126 (L dry kg^{-1}). An ethanol production technique based on milling pretreatment and enzymatic hydrolysis was developed [9].
- The theoretical ethanol yield was calculated by the U.S. Department of Energy, which assumed that both hexose and pentose sugars are fermented; therefore, ethanol can be produced from rice straw at a rate of 111.5 gallons per dry ton. Depending on the feedstock and the process, the actual yield could be anywhere from 60% to 90% of the theoretical value [26]. For this study, an ethanol yield of 60% of the theoretical yield was assumed, which would result in 65.9 gallons per dry ton of rice straw, or 0.25 (L dry kg^{-1}).

Table 4. Annual potential of ethanol production and gasoline substitution from rice straw.

	Ethanol yield (L dry kg^{-1})	Ethanol production (ML)	Gasoline equivalent (ML)
Case 1	0.126	1837	1225
Case 2	0.250	3645	2430

Table 4 shows the estimates of ethanol production potential from rice straw in the Mekong Delta and the substitution potential of this ethanol for gasoline consumption based on energy content. Depending on the ethanol yield basis applied, the estimated ethanol potential from rice straw in the Mekong Delta could be 1837 ML (case 1) or 3645 ML per year (case 2).

In case 1, the authentic experimental result—the ethanol yield from rice straw of about 0.126 L dry kg^{-1} was applied. This yield is similar to the yields obtained in some Japanese bioethanol plants that use rice straw as feedstock. At the Hokkaido Soft Cellulose Project Plant, the ethanol yield is around 0.13 (v/w) or 130 L dry ton^{-1} of rice straw. This plant uses an alkaline pretreatment, cellulase for saccharification, and yeast for ethanol fermentation of glucose, with no xylose fermentation (Personal communication).

In case 2, the estimation applied an ethanol yield of 60% of the theoretical yield, about 0.25 L dry kg^{-1}. This ethanol yield is almost the same as that obtained at the Soft Cellulose Bioethanol Plant in Akashi, Kobe, Japan. In this plant, 245 L of ethanol can be produced from one dry ton of rice straw, or the ethanol yield is 0.245 L dry kg^{-1}. The hydrothermal method is used for pretreatment. After milling, the rice straw is pretreated using steam at 130–300°C and 10 MPa. This pretreatment can automatically separate lignin, and hemicellulose into soluble and (mainly cellulose) insoluble fractions. Subsequently, saccharification and ethanol fermentation of hexose and pentose sugars are separately conducted. The efficacy of xylose utilization was confirmed (Personal communication).

According to these estimates, the quantity of ethanol potentially produced from rice straw in the Mekong Delta may substitute for an amount of imported gasoline of 1225 ML in case 1 and 2430 ML in case 2. The total gasoline consumption in Vietnam in 2008 was 3405 thousand tons or 4310 ML (100% imported) [27]. In other words, the ethanol production potential from rice straw in this region may substitute for 28.4% to 56.4% of the total gasoline consumption in Vietnam, as can be seen from 2008 statistics. Applying the case 1 ethanol yield (0.126 L dry kg^{-1}), ethanol produced from rice straw in An Giang alone can reach 287 ML year^{-1}. This level of production can meet the target of the Vietnamese government for producing biofuels by 2015, without using food crops such as sugarcane and cassava that have been cultivated for ethanol production [28].

Though rice-straw ethanol yields used for the estimations in this research can be practically achieved at some pilot ethanol plants in Japan, the cost of ethanol produced in Japan is still high for fuel use. Some of the reasons are the high costs of enzymes and rice straw and the small scale of ethanol production. The rice straw price in Japan was estimated to be about 15 JPY dry kg^{-1} (87 JPY = 1 USD) or 172 USD dry ton^{-1} in 2010, including transportation fees [29]. For the amount of rice straw collected in one hectare of paddy field in the Mekong Delta (about 9 dry tons), the current purchase price ranges from 72 to 82 USD for feeding cattle and mushroom cultivation or 8 to 9 USD dry ton^{-1} (not including transportation fees) [30]. Thus, rice-straw costs in the Delta could be cheaper by far than those in Japan. Additionally, the substantial amount of rice straw for large-scale ethanol production and low labor costs for bioethanol plant operation could reduce ethanol production costs in the region. To verify this expectation, an economic analysis for bioethanol production from rice straw in this region should be conducted.

At the current time, our estimation is considered as practical. The rice-straw ethanol yields used for estimating the ethanol production potential in the present study seem to be more conservative than those used in a previous analysis [31]. With the development of advanced techniques for more efficient hydrolysis and fermentation, the ethanol production potential from rice straw in this region could surpass our estimation. The ethanol production process employing rice straw will be a feasible technology in the near future [32].

5. CONCLUSION

The potential of ethanol production from agricultural residues in the Mekong Delta was assessed on the basis of feedstock availability and distribution. Rice production in the Mekong Delta was predominant in comparison to other crops, and generated an abundant supply of rice straw (28.67 MT year^{-1}). Rice straw accounted for 79% of the total agricultural residues generated in the Delta. With its substantial availability as well as its suitable composition for ethanol production, rice straw could be the main feedstock for ethanol production in this region; thus, the potential of ethanol production from other agricultural residues in this area was ignored. Considering the possible collection and other uses of rice straw, it was assumed that 50% of the rice straw generated annually could be used for sustainable ethanol production. The analysis of the distribution of rice straw by season and sub-region in the Delta showed a great potential of feedstock supply for bioethanol plants in the region. Rice straw is abundant, and provided mainly from the two main harvest seasons of spring and autumn rice. The areas with high densities of rice straw supply are located along the upper and mid-banks of the Hau and Tien Rivers in the following sub-regions: An Giang, Can Tho, Hau Giang, Kien Giang, Dong Thap, Vinh Long, Long An, and Tien Giang.

According to our estimation, the potential of ethanol production in the Delta could be 1837 ML year^{-1}, or up to 3645 ML year^{-1} (without or with xylose fermentation), using current rice-straw ethanol production technologies from Japan. This amount of ethanol could substitute for 28.4% to 56.4% of the total 2008 gasoline consumption in Vietnam. This research showed a high potential for ethanol production from rice straw in the Mekong Delta, which could promote rural development and reduce pollution caused by agricultural waste. As rice straw is readily available, non-reliant on additional land use, and produced on almost every farm, it thus offers the opportunity for the farmer to profit from ethanol production. Promoting ethanol production from rice straw in the Delta will contribute to the sustainable integration of local agriculture and bioenergy production as well as to the energy security of the entire country.

ACKNOWLEDGEMENT

This research was funded by the Asia Biomass Energy Researchers Invitation Program 2010—New Energy Foundation, Japan. The authors thank Dr. S. Yano for providing the experimental data for ethanol production from rice straw and Prof. N. Nakagoshi for his valuable comments.

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