Life cycle assessment of bioethanol produced from rice straw (RT-CaCCO process)

Poritosh Roy, Ken Tokuyasu, Takahiro Orikasa, Riki Shiroma, Jeung-yil Park, Nobutaka Nakamura and Takeo Shiina

1) National Food Research Institute, National Agriculture and Food Research Organization, Japan
2) School of Food, Agriculture and Environmental Sciences, Miyagi University, Japan
*shiina@affrc.go.jp

1. Introduction
Greenhouse gas (GHG) emission, which has increased remarkably due to tremendous energy use, has resulted in global warming, perhaps the most serious problem that humankind faces today. Liquid biofuels (biethanol and biodiesel) are widely recognized alternatives to fossil fuel. The use of lignocellulosic bioethanol has been emphasized because it does not compete with food. Therefore, this study attempts to estimate the net energy consumption, CO₂ emission and production cost of bioethanol produced from rice straw by the enzymatic hydrolysis process and identify the hotspots to improve the production process and to determine a cost effective and environmentally friendly production process.

2. Methodology
The Ministry of Agriculture, Forestry and Fisheries (MAFF) has committed to produce bioethanol from agri-residues, especially from rice straw (15000 kL/year in a plant) in Japan. Therefore, the plant capacity is assumed to be 15000 kL/year in this study. The LCA methodologies were used to evaluate the life cycle of bioethanol produced from rice straw. The functional unit (FU) of this study is defined as 1 L anhydrous bioethanol produced from rice straw. Figure 1 shows the schematic diagram of the life cycle of bioethanol produced from rice straw and the system boundary of this study. Lime pretreatment (CaCCO: calcium capturing by carbonation i.e., by CO₂; lime 10%1,2) was applied to the crushed rice straw (cv. Koshihikari; size: 3 mm) at room temperature (25°C) for 7 days. The CO₂ used in this process would be available as a byproduct from the fermentation/combustion processes1). The pretreated rice straw (10% in the slurry) was then allowed for simultaneous saccharification and fermentation (SSF) at 33°C for 80 h2). The enzyme loading is assumed to be 12 FPU/g-rice straw1,2). The bioethanol yield was considered to be 0.25 L/t-dry straw2). The experimental data (crushing and lime pretreatment) were collected from the bench scale bioethanol plant (BEP) at the National Food Research Institute Tsukuba, Japan. Based on these experimental data energy consumption in simultaneous saccharification and fermentation (SSF) process was worked out, and energy consumption for agitation and enzyme production3), conventional distillation4), vacuum extractive fermentation & distillation5) and purification6) were collected from the literatures. Three scenarios are established to determine if environmental friendly and economically viable bioethanol can be produced from rice straw. Table 1 shows the scenarios of this study.

3. Results and discussion
3.1 Net energy consumption and CO₂ emission
The energy and CO₂ emission breakdown for different scenarios are shown in Figures 2 and 3, respectively. The net energy consumption and the CO₂ emission are found to be dependent on the assumed scenarios. The difference in energy consumption and CO₂ emission are caused by the difference in transportation distance, SSF and distillation stages which are dependent feedstock demand and adopted technologies for different scenarios. The transportation energy is greater for S₃ and S₂ compared to that of S₁ because of the difference in feedstock demand and straw collection option (60% for S₃). The hotspots are distillation or enzyme production followed by SSF depending on the scenarios.

3.2 Production cost
The production cost of ethanol is also found to be dependent on...
the assumed scenarios. The production cost is estimated to be lowest for the scenario S3, followed by S2 and the highest for the S1 (Fig. 4) because of the difference in the transportation, fermentation, distillation, feedstock and the fixed cost among the assumed scenarios. Total production costs are found to be 87.6, 129.6 and 137.6 ¥/L for S3, S2 and S1, respectively. For scenarios S1 and S2 the hotspots are found to be feedstock or fixed cost followed by the enzyme cost. However, in the case scenario S3 the hotspots are fixed cost or enzyme cost followed by feedstock cost.

3.3 Discussion

Despite the environmental benefits of bioethanol produces from rice straw, its economic viability is doubtful unless innovative technologies along with the renewable energy policy and stakeholders participation are considered. The biotechnological revolution is must to reduce production cost of bioethanol from rice straw, especially in the field of enzyme, microorganisms and feedstock which can easily be converted for bioethanol. Recycling of lime uses in the pretreatment process and the introduction of innovative harvesting machine which would be able to collect straw along with rice in a single pass may also reduce the cost of bioethanol. Another promising alternative for compensating production cost is to extract valuable byproducts. It is worthy to note that this is a highly optimistic (hypothetical) study and all the data neither to the Japanese context, nor from the same plant size. Therefore, in depth studies are demanded for each stages of the life cycle of bioethanol from rice straw, especially enzyme and yeast production, SSF, and distillation for any future investment and commercial production.

4. Conclusion

This study reveals that adaptation of innovative technology, and renewable energy policy and stakeholders participation (i.e., change in scenarios) not only reduce net energy consumption and CO₂ emission but also the production cost of bioethanol from rice straw, may enable to compete with its counter part and encourage more investment in the bioethanol industry.

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5. Reference