Techno-Economic Analysis of Lignocellulose to Fuel Ethanol Biorefinery

Hua-Jiang Huang[1], Shri Ramaswamy[1], **Al-Dajani Waleed**[1], **Ulrike Tschirner**[1] and **Richard A. Cairncross**[2], (1) Department of Bioproducts and Biosystems Engineering, University of Minnesota, 2004 Folwell Ave, St. Paul, MN 55108, (2) Chemical & Biological Engineering, Drexel University, 3141 Chestnut St, Philadelphia, PA 19104

There has been an increasing interests in the conversion of lignocellulosic biomass to fuel grade ethanol in the recent years due to the need for minimizing oil imports, increasing oil prices and increasing global oil consumption and the need for alternative renewable energy and the requirement of minimizing greenhouse gas (GHG) emissions caused by the use of fossil fuel (Morrow 2006). At present, number of corn-to-ethanol plants have been commercially built and operating around the world, while no process for lignocellulosic biomass-to-ethanol, or cellulosic ethanol, has yet been commercially available because of existing technical, economic, and commercial barriers. However, cellulosic ethanol can be more effective and promising as an alternative renewable bio-fuel than corn ethanol in the long run because it could greatly reduce the net greenhouse gas (GHG) emissions as well as higher net fossil fuel displacement potential. With large-scale planting of fast-growing cellulosic energy crops such as hybrid poplar and switchgrass on different types of lands through plant breeding and improved crop management, the purchase cost of feed stocks could also be relatively lower (Kszos 2006). In this paper, a whole lignocellulosic biomass-to-ethanol biorefinery is designed and modeled. The overall process efficiency and economic performance of the biorefinery to manufacture liquid fuels from lignocelluloses is studied. Environmental consideration is also taken into account.

The effects of biomass species and chemical composition on the overall process efficiency and economic performance to manufacture ethanol from lignocellulose was firstly studied. Comparative studies considering four different aspects are reported here. First is a comparison of ethanol production and excess electricity generated between different biomass species. Results show that, at the same feedstock rate of 2000 Mg/day, the ethanol production capacity are in the following order: (low) switchgrass < hybrid poplar/corn stover < aspen (high), while the excess electricity generated are as follows: (low) aspen < corn stover < hybrid poplar/switchgrass (high). Second is the effect of chemical composition of the biomass species on ethanol production and excess electricity generated. It shows that the amount of holocellulose of the feedstock are in the same order as the ethanol production, and the ethanol production is largely linear with holocellulose composition of various species. However, the relationship between excess electricity generated and non-holocellulose combustible component is nonlinear. Third is the effect of biomass species on major waste streams. It is found that aspen wood has the lowest amount of waste effluent, switchgrass the highest, hybrid poplar and corn stover are in between. The last is overall comparison of four species**.** Our result predicts that all biomass species can be used to produce ethanol at reasonable cost, with aspen showing the lowest cost and the lowest waste effluents than the other biomass species. Of course, the availability of aspen for ethanol manufacture competing with other forest products is very much dependent on the geographic region in the world. Hybrid poplar and switchgrass are the two promising future energy crops, while corn stover is a potential feedstock to produce ethanol with low ethanol production cost at the present time.

The effect of plant size/capacity on the overall process efficiency and economic performance to manufacture ethanol from lignocelluloses was also studied. First, a simplified method to estimate the transportation costs and hence the feedstock delivered costs was described in detail. It was found that the delivered costs estimated increase linearly with plant size for various biomass species in the following order: (high) hybrid poplar > corn stover > switchgrass. Second, it was shown that both the ethanol production and the excess electricity generated increase linearly with the plant size. Third, the ethanol production costs decrease with the increase in plant size, and relatively more suitable plant sizes are found in the range from 2000 to 4000 dry Mg/day. Fourth, the major waste emissions (gypsum, ash and the total gas: CO_2, CO, NO_2, SO_2 and CH_4) increase linearly with the plant size, and results showed that the four species have similar amount of gypsum emissions, but different ash emissions in the order: switchgrass > corn stover > hybrid poplar > aspen wood, and different total gas emissions: hybrid poplar > switchgrass > aspen wood > corn stover. At last, the combined effects of both the feed stock availability and feed stock delivered price on ethanol production costs has also been shown.

The biorefinery model can help us better understand the overall process and better predict the operating cost and environmental impacts and the overall viability of the biorefinery. Our result predicts that lignocellulose to ethanol biorefinery is highly feasible and the economic and environmental performance compares favorably to today's corn-to-ethanol.

[References]

William R. Morrow, W. Michael Griffin, and H. Scott Matthews. Modeling Switchgrass Derived Cellulosic Ethanol Distribution in the United States. Environmental Science & Technology, 40(9):2877-2886, 2006

Lynn Adams Kszos, Bioenergy from Switchgrass: Reducing Production Costs by Improving Yield And Optimizing Crop Management, http://www.ornl.gov/~webworks/cppr/y2001/pres/114121.pdf (May 14, 2006)

Aden A, Ruth M, Ibsen K, Jechura J, Neeves K, Sheehan J et al. Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover. NREL report TP-510-32438. 2002.

Wooley R, Ruth M, Sheehan J and Ibsen K. Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis current and futuristic scenarios—website: http://www.ott.doe.gov/biofuels/process_engineering.html. NREL report TP-580-26157. 1999.