Evaluating the Location of a Cellulosic Biorefinery Based on the Delivered Costs and Transportation Emissions of Feedstock: A Case Study of Tennessee

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Locating a Cellulosic Biorefinery in Tennessee by Evaluating Plant-gate Costs and Trucking Emissions of Feedstock

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INTRODUCTION

The supply chain system of biomass feedstock is crucial to the development of the cellulosic biofuel industry because of the importance of the quality and quantity associated with the bulky feedstock to the biofuel conversion process. Moreover, the large amount of biomass to be delivered to a commercial-scale biorefinery will likely create more traffic volume on roadways than the hauls of conventional feedstock, e.g. corn, due to substantial difference in feedstock density. The environmental impacts of increased traffic from LCB feedstock hauling have received increasing attention in the literature recently since highway vehicles currently are a major contributor to carbon monoxide (CO), NO_x, and volatile organic compounds in the United States. Thus, the trucking emissions of LCB feedstock hauling, together with the feedstock cost, under various supply systems needs to be examined for developing a commercial biorefinery.

OBJECTIVES

Given the potential for developing a switchgrass-based biofuel industry in Tennessee, this study evaluates the optimal locations of biorefineries in three regions of Tennessee based on the feedstock plant-gate costs and transportation emissions. Our specific research objectives are:

1. to develop a comprehensive estimate of vehicle emissions caused by delivery of switchgrass to a commercial-scale biorefinery site, and
2. to evaluate tradeoffs in plant gate feedstock costs and transportation emissions for alternative biorefinery locations in Tennessee.

ANALYSIS APPROACH

The analytical approach is presented in Figure 1:

1. The least-cost feedstock draw area and location of the biorefinery was identified for each of three regions in Tennessee by minimizing feedstock plant-gate costs.
2. The existing traffic emissions on the road networks (the *baseline*) and the additional emissions produced from feedstock transportation (the *project*) were estimated

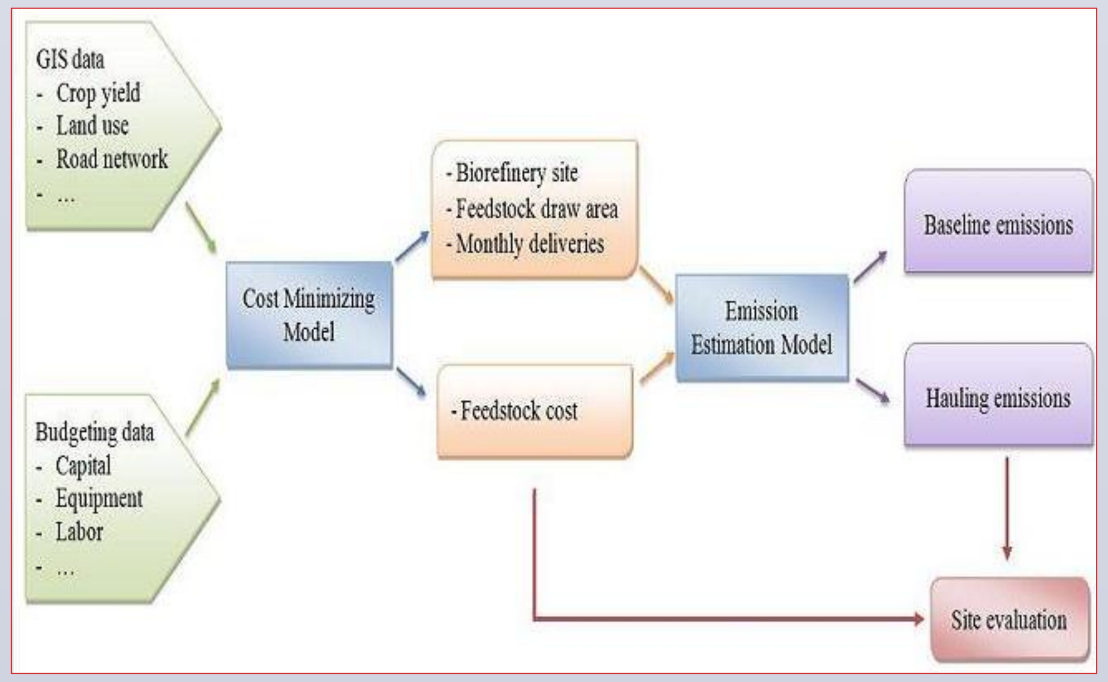

Figure 1. Analytical flow

MODEL ASSUMPTIONS & DATA

Assumptions & data in the cost minimizing model:

- Capacity of the commercial-scale biorefinery is 50 million gallons of biofuel per year (MGY)
- Large round bale (LRB) and large square bale (LSB) harvest, storage, and transportation systems were evaluated.
- Switchgrass is harvested once per year in October−February.
- Dry matter losses for storage periods were modeled for up to 365 days for the LRB and LSB systems.
- Potential locations for the biorefineries was limited to feasible industrial parks with access to water, power, and roads, as well as sufficient storage space in each region (see Figure 2).
- Traditional crop yields were from the SSURGO database at the sub-county level in USDA/NASS; area in each traditional crop for crop zone was from the cropland layer database in NASS.
- Yield of mature switchgrass from POLYSYS model ranges between 8.0 and 9.4 dry ton/acre (see Figure 3).

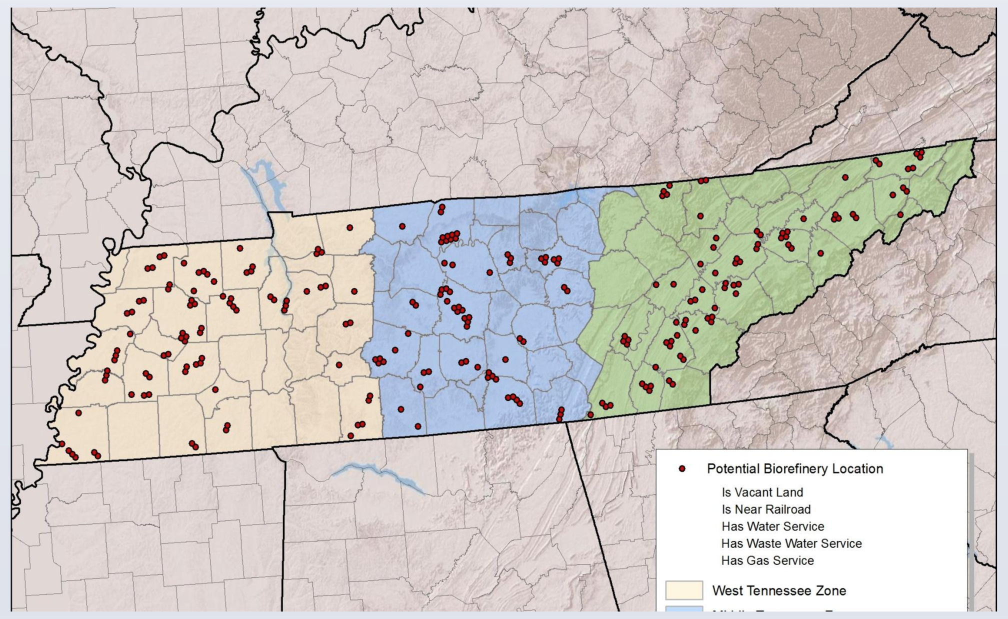

Figure 2. Potential industrial parks to site biorefinery

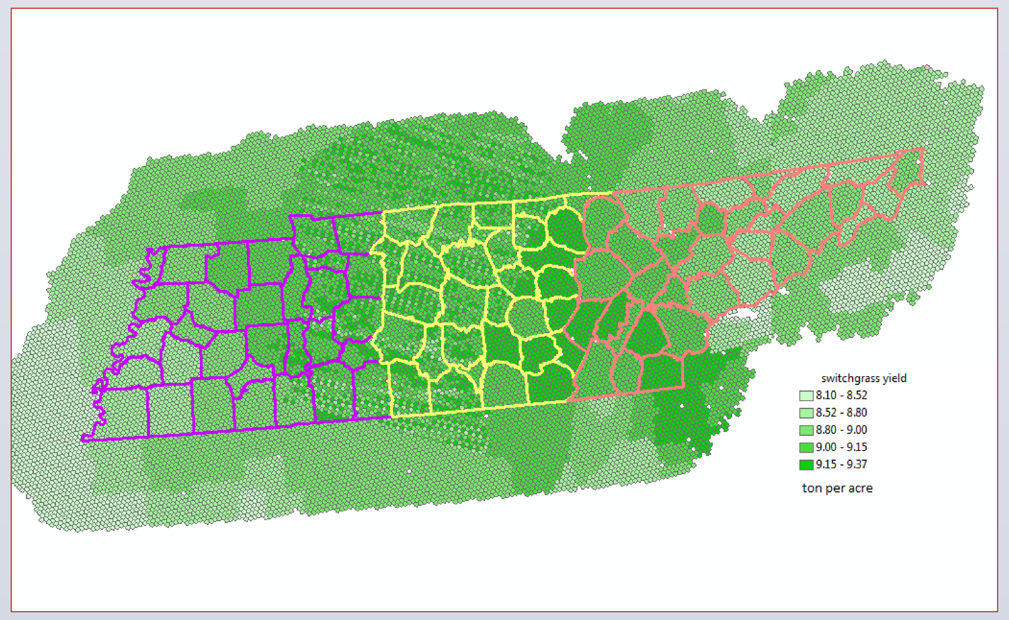

Figure 3. Potential yield of switchgrass

Assumptions & data used in the emission model :

- U.S. EPA's Motor Vehicle Emissions Simulator version 2010a was used to estimate air pollution emissions from vehicles
- Air pollutants modeled include NO_x, total primary PM_{10} and $PM_{2.5}$, and the equivalent CO_2.
- A representative month of 2010 that best characterized each season of the year was selected.
- A single county was chosen to represent one of the general regions in the state.

EMPIRICAL RESULTS

Table 1 summarizes the optimal plant-gate costs of switchgrass for a 50-MGY biorefinery using the large round bale (LRB) and large square bale (LSB) systems by region. The LSB system has the cost advantage of $3 to $4 per dry ton when comparing to the LRB system. The feedstock draw area and biorefinery location with the least cost in each region using LSB systems are illustrated in Figure 4.

Table 1. Plant-gate Cost of Switchgrass for a 50-MGY Biorefinery

	LRB			LSB		
	East	Middle	West	East	Middle	West
Storage option (top/bottom)	untarp/ground			tarp/wood pallet		
Total Feedstock Cost (million $)	**$ 48.2**	**$ 47.1**	**$ 48.4**	**$ 46.3**	**$ 45.4**	**$ 46.4**
Production	$ 9.3	$ 9.1	$ 9.0	$ 9.2	$ 9.3	$ 9.2
Harvest	$ 27.0	$ 26.6	$ 26.5	$ 23.9	$ 23.9	$ 23.9
Storage	$ -	$ -	$ -	$ 3.3	$ 3.3	$ 3.3
Transportation	$ 11.9	$ 11.4	$ 12.9	$ 9.9	$ 8.8	$ 10.0
Feedstock Cost/dt	$ 73	$ 72	$ 74	$ 70	$ 69	$ 70
Biorefinery Location	Greene	Robertson	Lawrence	McMinn	Robertson	Lawrence
Total Harvested Area (acres)	80,673	78,038	77,699	79,715	80,061	79,680

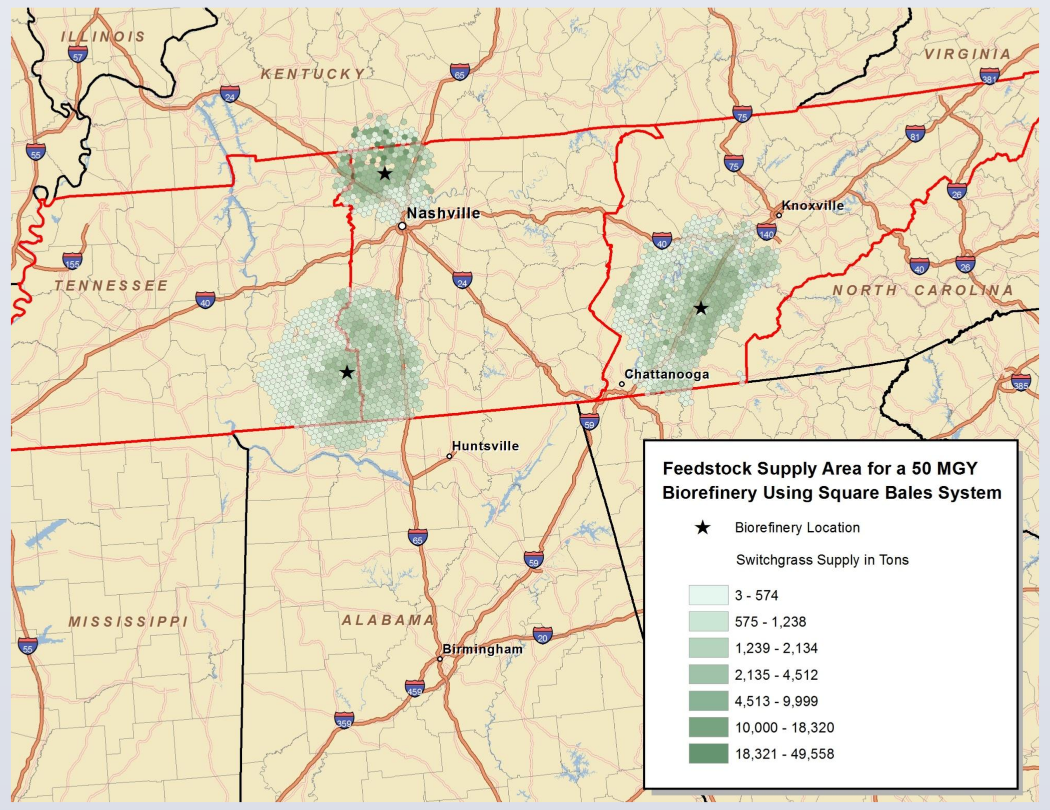

Figure 4. Feedstock draw area for a 50-MGY biorefinery using LSB system

Table 2 summarizes the emissions in the project case and the increase rate between the baseline and the project by supply chain systems for the optimal site of biorefinery in each region. For the identical biorefinery capacity in all regions, switchgrass hauling to the optimal site in west Tennessee using LRB system generated the highest vehicle miles traveled (VMT), hence the most emissions.

Table 2. Emissions from Switchgrass Hauling by Bale System and Biorefinery Location

	LRB			LSB		
	East	Middle	West	East	Middle	West
Biorefinery location	Greene	Robertson	Lawrence	McMinn	Robertson	Lawrence
# of counties related	7	8	11	17	8	11
Average road slope	3.79	2.42	2.93	3.11	2.26	2.64
VMTs (miles)	1,477,878	1,431,231	2,259,666	1,932,794	1,231,110	1,968,441
Project case (tons)						
NO_x	38.8	35.7	56.7	48.2	30.3	49.4
CO_2	4,379.7	3,899.3	6,221.5	5,268.1	3,303.4	5,432.5
PM_{10}	2.5	2.2	3.5	2.9	1.8	3.1
$PM_{2.5}$	2.2	2.0	3.2	2.6	1.6	2.8
Emission increase (%)						
NO_x	0.25	0.14	0.48	0.12	0.12	0.42
CO_2	0.10	0.05	0.20	0.05	0.04	0.17
PM_{10}	0.38	0.18	0.74	0.18	0.15	0.65
$PM_{2.5}$	0.44	0.22	0.84	0.21	0.18	0.74

Figure 5 presents both plant-gate cost and CO_2 emissions of hauling switchgrass feedstock to a potential 50-MGY biorefinery using alternative supply chain systems in all three regions. The biorefinery located in central Tennessee (Robertson County) adopting the LSB system was found to be the most sustainable with the least costs and feedstock transportation emissions.

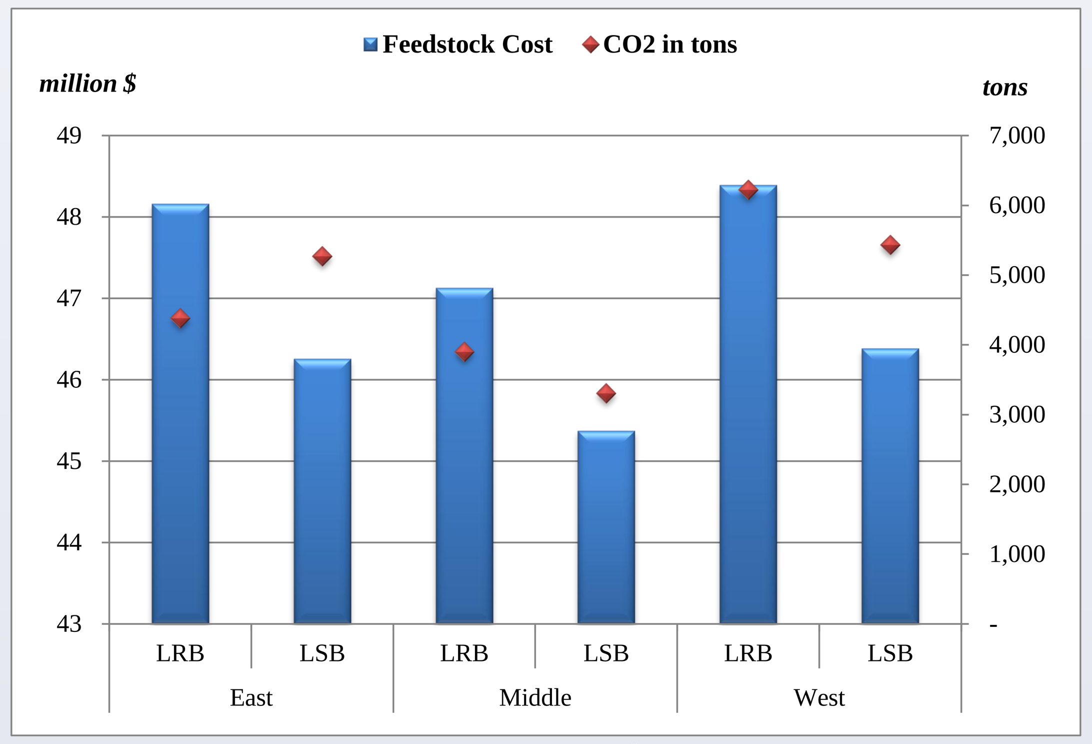

Figure 5. Total plant-gate costs and CO^2 emissions of switchgrass deliveries to a 50-MGY biorefinery in Tennessee

CONCLUSIONS

This study estimated the cost of producing, harvesting, storing, and transporting switchgrass along with associated emissions linked to hauling the feedstock using two commonly utilized feedstock supply chain system in east, central and west Tennessee. Our results suggest that:

1. The large square bale system is more cost efficient over the large round bale system due to the efficiency in harvesting and transportation.
2. Switchgrass delivery to the optimal site in central Tennessee using large square bale system expected to increase the emissions of NO_X, CO_2, PM_{10}, and $PM_{2.5}$ in related 8 counties by 0.12%, 0.04%, 0.15%, and 0.18%, respectively, when comparing with the overall baseline emissions.
3. Considering both feedstock cost and feedstock trucking emissions, the city of Springfield, TN near the intersection of U.S. Highways 431 and 41 (about 25 miles north of Nashville, TN, and 10 miles from the Kentucky border) is identified to be the most preferred site to establish a 50-MGY switchgrass-based biorefinery.

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