The Transportation Emission Impact of the Biomass Feedstock Traffic of A Potential Commercial-Scale Biorefinery in East Tennessee

T. Edward Yu[1] (Corresponding author)
E-mail: tyu1@utk.edu

Joshua S. Fu[2]
E-mail: jsfu@utk.edu

James A. Larson[1]
E-mail: jlarson2@utk.edu

Burton C. English[1]
E-mail: benglish@utk.edu

Daniel De La Torre Ugarte[1]
E-mail: danieltu@utk.edu

Bradly Wilson[1]
E-mail: driver8@utk.edu

Jeongran Yun[2]
E-mail: jyun@utk.edu

Yuan Gao[3]
E-mail: Y.Gao@cgiar.org

Jimmy Calcagno, III[2]
E-mail: jacal@utk.edu

[1]Department of Agricultural & Resource Economics, University of Tennessee, Knoxville, TN 37996-4518, Phone: (865) 974-7231, Fax: (865) 974-7484

[2]Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN 37996-4518, Phone: (865) 974-2629, Fax: (865) 974-2669

[3]2033 K Street, NW, Room 8007B, International Food Policy Research Institute, Washington, DC 20006-1002, Phone: (202) 862-8183, Fax: (202) 467-4439

Abstract The logistics required to supply biomass feedstock a refinery is crucial to the development of the cellulosic biofuel industry because of the importance of the quality and quantity and bulky nature associated with cellulosic feedstock to the biofuel conversion process. In addition, the potential social and environmental impact of biomass feedstock transportation has also received increasing attention due to the expansion of truck traffic on the current road system. This study applies a spatial-oriented mixed-integer mathematical programming model linked to a GIS resource model to generate a least cost solution of a typical feedstock harvest and logistic system for a potential biorefinery with the capacity of 50 million gallons per year. Moreover, U.S. EPA's MOVES2010a was used to estimate the baseline emissions for 2010 with national scale option in study region and additional emissions generated from hauling those feedstock with project scale option. Results showed that the transportation cost accounted for nearly one-quarter of total plant gate costs of the large round bales. Also, it was estimated that the biorefinery received about 50,000 truckloads per year, hence creating annually 100,000 truck trips (or 274 truck trips per day) on the road linking the entrance of the biorefinery to the supply regions. The overall VMT increase resulting from additional feedstock truck traffics was 3.7 million miles and the emissions of NO_X, CO_2, PM_{10}, and $PM_{2.5}$ emissions increased by 0.32%, 0.13%, 0.60%, and 0.71%, respectively, in these 13 counties studied when comparing with the overall baseline emissions.

Keywords: bioenergy, feedstock transportation, trucking emissions, MOVES model

INTRODUCTION

Establishing a commercially viable lignocellulosic biomass (LCB) biofuels industry is currently one of the major focuses of renewable energy development in the United States (Osborne, 2010). Nationally, various policy programs, such as blender tax credits, federal legislation of biofuel mandates enacted in 2007, and the grant/loan program for establishing biomass feedstocks and constructing LCB-based biofuel refineries under the Food, Conservation, and Energy Act of 2008, have been placed to accelerate the commercialization of advanced biofuels, including biofuels generated from LCB feedstock. Regionally, several states have also created incentive programs to develop local bioenergy industries. Tennessee is one of the leading states and has committed $70 million to the Tennessee Biofuels Initiative (TBI) to improve the economic feasibility of biofuel production since 2007 (Goodman, 2011).

With the support of TBI, DuPont Danisco Cellulosic Ethanol (DDCE) partnered with Genera Energy LLC, a profit company formed by UT under the Initiative, to operate a demonstration facility using corncobs and switchgrass as feedstocks in Vonore, TN, in January 2010. With the success in the conversion technologies for the LCB-based biofuels production, DDCE has planned to build a commercial-scale corn-cob ethanol plant in Iowa by 2012 and a switchgrass-based biorefinery in East Tennessee by 2014 (Brass, 2011). The planned establishment of the commercial-scale biorefinery is expected to affect the transportation on the road networks linking feedstock supply areas and the biorefinery. Comparing to biorefineries using traditional field crops, the delivery of the LCB feedstock for biorefinery will create a higher demand on the road systems (in terms of truck loads) due to the low density of LCB feedstock. For example, we estimate that a switchgrass-based biofuel plant producing 189.25 kl of ethanol year^{-1} will need nearly 135 deliveries per day of large round bales by semi-truck, which may create social and environmental impacts on the communities around the biorefinery.

The social and environmental impacts of increased traffic induced by LCB feedstock shipments have received increasing attention in recent literature. For instance, Kumar et al. (2006) applied a multi-criteria assessment methodology that considers economic, social, environmental, and technical factors to rank alternatives for LCB feedstock transportation. For the impact of increased traffic from LCB feedstock logistics, Thornley (2008) indicated that the proximity of conversion or preprocessing/pretreatment facilities to LCB feedstock is directly linked to transport emissions. Nitrogen oxides (NO_x) emissions from harvesting and tractor operations in the field are also significant. According to the U.S. Environmental Protection Agency (EPA), highway vehicles currently are a major contributor to carbon monoxide (CO), NO_x, and volatile organic compounds (VOC) in the United States. Heavy duty trucks accounted for 50%, 56%, and 68% of the respective NO_x, particulate matter (PM_{10}), and fine particle ($PM_{2.5}$) emissions produced by all vehicles on highways in 2005 (U.S. EPA, 2010).

The potential emissions from additional road traffic caused by LCB feedstock logistics require thorough examination because the emissions may be a barrier to the development of a *sustainable* industry. According to the Clean Air Act, every facility operating an air contaminant source is required to obtain air pollution permits (construction permits and operating permits) from U.S. EPA. Title V operating permit program applies to any facilities that emit or have potential to emit more than 91 Mg year^{-1} of any air pollutant, 9 Mg year^{-1} of any hazardous air pollutant or 23 Mg year^{-1} of any combination of hazardous air pollutants (U.S. Code, 2011). To protect air quality, a facility that has a permit and fails to comply with the provisions, stipulations or compliance schedules specified in the permit, the operating permit may be suspended or revoked with penalties for each violation. Thus, understanding the potential transportation emission impact of LCB feedstock traffic is important for the biorefinery to plan a feedstock harvest and logistic system that benefits the development of a LCB biofuel industry and the environment of local communities.

The objective of this study is to estimate the emission impact of feedstock delivery to a commercial-scale LCB biorefinery. Given the current progress of the pilot LCB to ethanol plant in Vonore, TN, and the potential of developing an industrialized LCB biofuel industry in East Tennessee, this study estimated the least cost of supplying switchgrass to a potential commercial-scale biorefinery in that region under a commonly used harvest and logistic system using a spatially-oriented, mixed-integer mathematical programming model linking with a geographic information system (GIS) resource model. Also, the Motor Vehicle Emissions Simulator (MOVES) model developed by U.S. EPA was utilized to calculate the emissions of truck traffic moving feedstock from the field to the biorefinery for a feedstock harvest and logistic system. This study has a great potential to assist the long-term development of the emerging biofuels industry in Tennessee and other states that are engaged to biomass energy sector.

METHODS AND DATA

Two major steps were conducted in the analyses. First, feedstock area and the location of the potential commercial-scale biorefinery were determined for the harvest and logistic system by minimizing the feedstock delivered costs. Also, monthly truck traffic to deliver feedstock through the economic links between feedstock supply area and the biorefinery based on the real road networks were identified. In the second step, the additional emissions produced from truck traffic to deliver feedstocks were estimated and evaluated in the analysis.

Study Area

The potential area of feedstock supply for a commercial-scale biorefinery in this study covered 13 counties in East Tennessee (Anderson, Blount, Bradley, Cumberland, Knox, Loudon, McMinn, Meigs, Monroe, Morgan, Polk, Rhea, and Roane) because of their geographic connection with the pilot LCB biofuel plant in Monroe County, Tennessee (Figure 1). The 13 counties were divided into 1,144 13 km^2 hexagons, excluding the federal and state land areas. The details of the availability of switchgrass feedstock and the location of industrial parks with access to major road networks were also obtained from a high-resolution GIS resource model, BioFLAME (Wilson, 2011). Potential locations of 163 industrial park sites for the commercial-scale biorefinery along with the road networks were presented in Figure 1.

Logistics Cost under Alternative Harvest and Logistic Systems

This study applied a spatially-oriented mixed-integer mathematical programming model (BeSTA), extended from Wang (2009), that incorporates data generated from BioFLAME and a simulation model (English et al., 2006) to analyze the cost of two LCB feedstock harvest and logistic systems. The objective of this BeSTA model is to minimize total feedstock plant gate cost of producing, harvesting, storing and transporting feedstock, subject to the constrains on feedstock production availability and the demand of biorefinery for feedstock. The balance of monthly inventory and delivery of feedstock was also maintained to assure sufficient feedstock supply for the biorefinery. In addition, the dry matter loss during feedstock harvest, storage and transportation was incorporated to balance the final delivery of feedstock and the demand of biorefinery. The detailed structure of BeSTA model is available in Gao (2011).

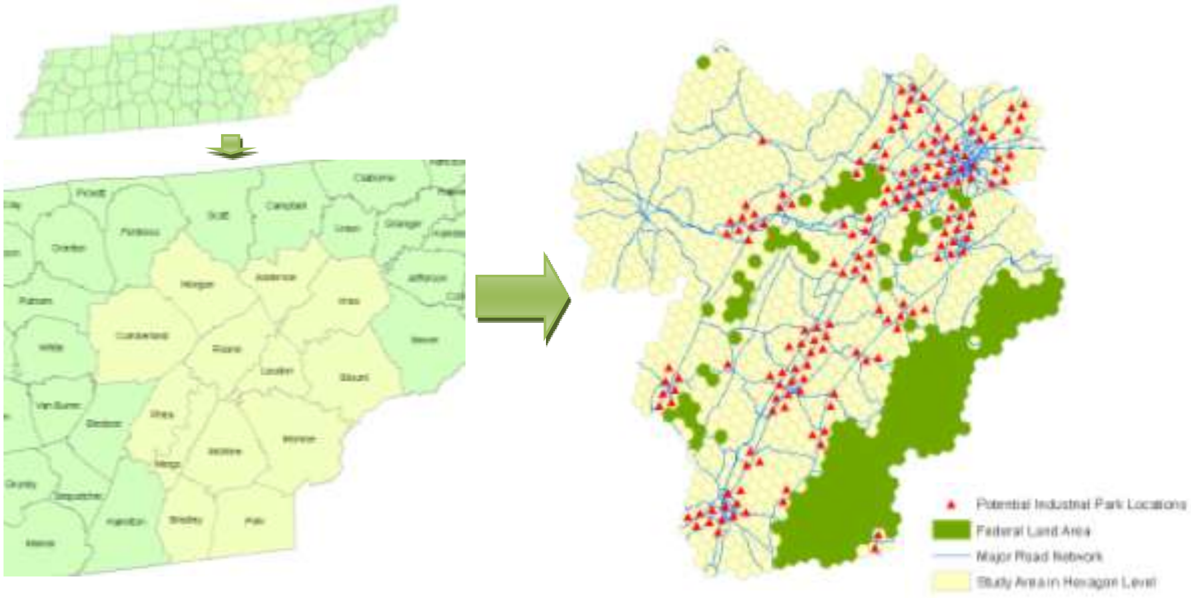

Figure 1 Potential area of feedstock production and the biorefinery in study

The feedstock harvest and logistic system under evaluation was the *large round bale* system, which currently is widely used for hay production in the study region. Remote sensing data is used to analyze feedstock availability at the sub-county level. The feedstock price was determined by its production cost, or the price level at which farmers are willing to substitute traditional cropping activities with the LCB feedstock, whichever is larger. The harvest cost consists of machinery and labor costs used for mowing, raking, baling, and loading. Storage cost includes the materials (plastic tarp and wooden pallet) used to protect those bales stored on the edge of field, and the labor and tractors for handling those materials and bales. Storage protection is not applied to bales directly delivered to biorefinery during harvest season. Transportation cost incorporates the loading and unloading costs of feedstock bales using tractors with front-end loaders, and the operation cost of semi-truck trailers and drivers for delivering bales. The transportation cost from feedstock area to the biorefinery was estimated based on the distance derived from the real street network in the region. The hauling distance from the field to the biorefinery was calculated as the distance between center point of the pixel in which feedstock was produced and the center point of the pixel where the biorefinery was located.

By minimizing the total plant gate costs of feedstock, the BeSTA model determined the feedstock production area, location of the biorefinery, and monthly feedstock delivery schedule. By mapping this information to the BioFLAME model, the shortest path routes (favoring major roads) between the biorefinery and each supply area along with the number of truckloads of feedstock being hauled along these routes were generated. The BioFLAME model then extracted the individual links of road that make up each route and attaches the truck volume information. Truck traffic flows on the road system were used as the inputs for estimating the emissions produced by LCB feedstock transportation in the next step.

The capacity assumption of the potential commercial-scale biorefinery was 189.25 kl year^{-1} of ethanol based on an industrial source. It was assumed that switchgrass was the major feedstock given the advantage of producing this energy crop in East Tennessee (Wright 2007). Nearly 596,555 dry Mg year^{-1} of switchgrass was required to maintain the year-round operation of the biorefinery based on a conversion rate of 0.32 kl dry Mg^{-1} (Wang, Saricks and Santini, 1999). It was assumed that a switchgrass field was harvested once per year, sometime between November to February, to minimize the fertilizer costs for maintaining nutrients in switchgrass and maximize the LCB for conversion to ethanol. The data of switchgrass yield and soil type was obtained from BioFLAME. The cost of labor, equipment and vehicles were obtained from Gao (2011) and Larson et al. (2010).

Truck Traffic Emissions under Alternative Harvest and logistic systems

As of March 2, 2010, the U.S. Environmental Protection Agency (EPA) approved a new mobile source emissions model, Motor Vehicle Emissions Simulator model (MOVES2010) for official use outside of California in state implementation plans (SIP) and air quality transportation conformity analysis, as a replacement for MOBILE6.2.(U.S. EPA, 2010) Given MOVES2010 allows customization to local areas and project level, this model can be used for various applications such as local air quality and transportation planning, assessment of emission impacts due to changes in vehicle speed, and local emission impacts of specific transportation projects.

The latest version of the MOVES model (MOVES2010a) was used to estimate the baseline emissions for the study area and the emissions of heavy duty truck from increasing traffic flows estimated from the study. The baseline emissions were compared with increased emissions estimated using the additional traffic flow on each road link generated from the BioFLAME model. The baseline emissions for all vehicles in the area were estimated for the year of 2010 using the national scale. The emissions were calculated for all hours, seven days a week and all months. Project scale in MOVES was used to estimate emissions from additional truck flows of feedstock hauling. Based on the traffic flows each month, links were defined. The information on road links includes link volume, link length, and link average grade. The traffic flows consider round trips. The model was run for each county and each month for a diesel-fueled combination short-haul truck with a rural unrestricted access road type. For this study, emissions were estimated for the start and end hours from 10:00 am to 10:59 am to represent off-peak hour. Default age distribution of trucks, fuel supply and formulation, and meteorology were used. Average speed option was chosen. For the average speed, speed limit on the link was utilized. Emission rates in grams km^{-1} for a truck were derived for each road link and used to calculate emissions. There were 182 sets of runs for the round trip, considering combination of county and month. The number of links for each run varied from 2 links to 1629 links. The model runtime varied depending on the number of links and specification of computers. In the case of the model run with 1629 links, it took 492 minutes to run using a computer with a AMD Athlon™ 64 X2 dual core processor 6000+ 3.01 GHz with 960 MB of RAM.

RESULTS

Table 1 presents the total cost of switchgrass for a 189.25 kl year^{-1} biorefinery under the large round bale harvest system. The total cost for delivering 596,555 dry Mg year^{-1} of large round bales was estimated at nearly $51.2 million, or $86 dry Mg^{-1}. Harvest cost associated with the round balers accounted for more than half of the total plant gate cost, whereas transportation cost was estimated at about 25% of total cost in the round bale system. The feedstock supply area, biorefinery location, and the routes linking the field to the biorefinery under round bale system are illustrated in Figure 3. The feedstock supply area covered all 13 counties. The feedstock was supplied by land located within 50 miles of the biorefinery, thus making trucking the most efficient mode. The plant was suggested to be positioned in the northwest corner of Monroe County along Interstate 75.

Table 1 Total Plant Gate Costs of Switchgrass under the Large Round Bale Harvest and Logistic System

	Round Bale System	Percent of Total Cost
Production Cost	$ 8,784,030	17.2%
Harvest Cost	$ 25,962,170	50.7%
Storage Cost	$ 3,762,403	7.4%
Transportation Cost	$ 12,659,190	24.7%
Total Plant gate cost	$ 51,167,800	

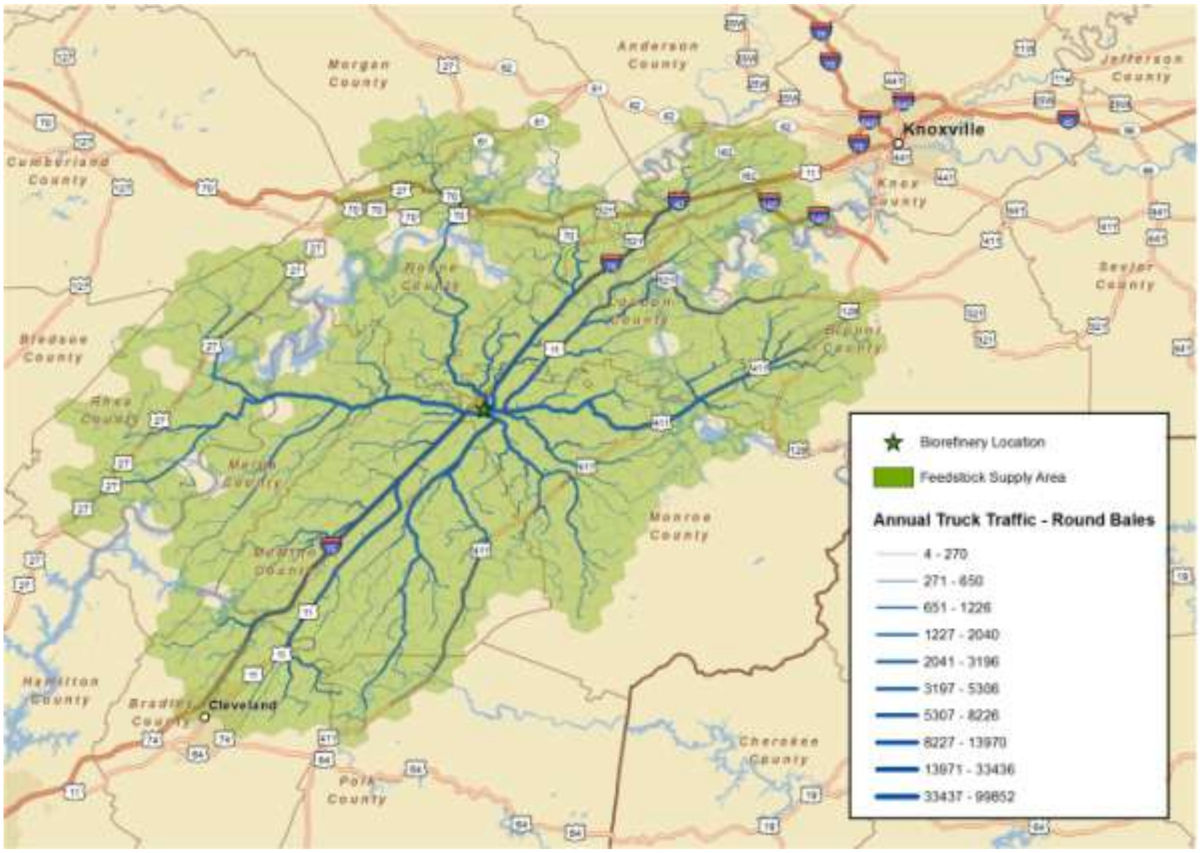

Figure 3 Annual truck traffic of switchgrass in round bales to biorefinery

The semi-truck traffic for each link presented in Figure 3 is annual volume aggregated from the monthly deliveries of switchgrass from supply areas to the biorefinery in the model. As expected, the additional traffic in those feedstock supply regions was modest. However, the traffic on major roads and interstates increased substantially when those individual deliveries entered the system. The map, representing the round-trips of trucks between all supply areas and the biorefinery, shows that feedstock shipments to the biorefinery could potentially generate an additional 100,000 truck trips per year on the roads linking to the entrance of the biorefinery under the round bale system. The delivery of switchgrass to the biorefinery increased truck volume considerably on major highways, such as I-75 and state highway 68, and the local road connecting to the biorefinery. By converting this volume into average daily traffic, the estimated annual average truck trips increased about 150 trips per day on the major highways and more than 270 trips per day on the links connecting the entrance of the biorefinery (see Figure 4).

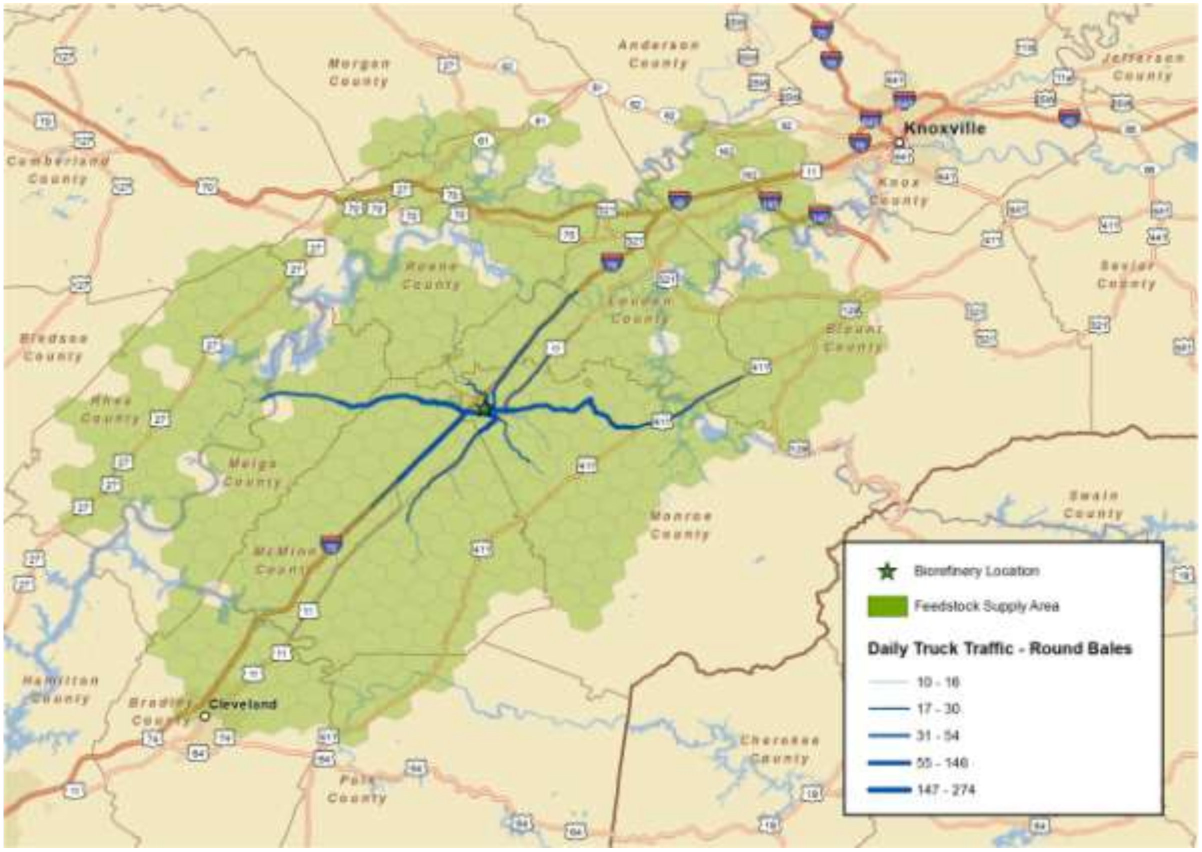

Figure 4 Annual average daily truck traffic of switchgrass in round bales to biorefinery

Emissions were estimated for each link, using the estimated additional truck traffic in each road link generated from the BioFLAME model. The road link information included truck volumes, link length, road grades and average speed. Emissions were estimated for each month based on the traffic volumes by month from the logistic system and were aggregated into annual emissions for each county. Additional emission of CO_2 generated from switchgrass feedstock delivery on the road system is mapped in Figure 5. Driven by the additional 100,000 trucks moving feedstock on the busiest road system in the study region, it was estimated that the CO_2 emission increased by more than 43 milligrams (Mg) per month on links connecting to the entrance of the biorefinery. In the major road networks, the CO2 emission also increased around 27 Mg per month. The similar pattern was also found in other emissions, such as NO_x, PM_{10}, and $PM_{2.5}$.

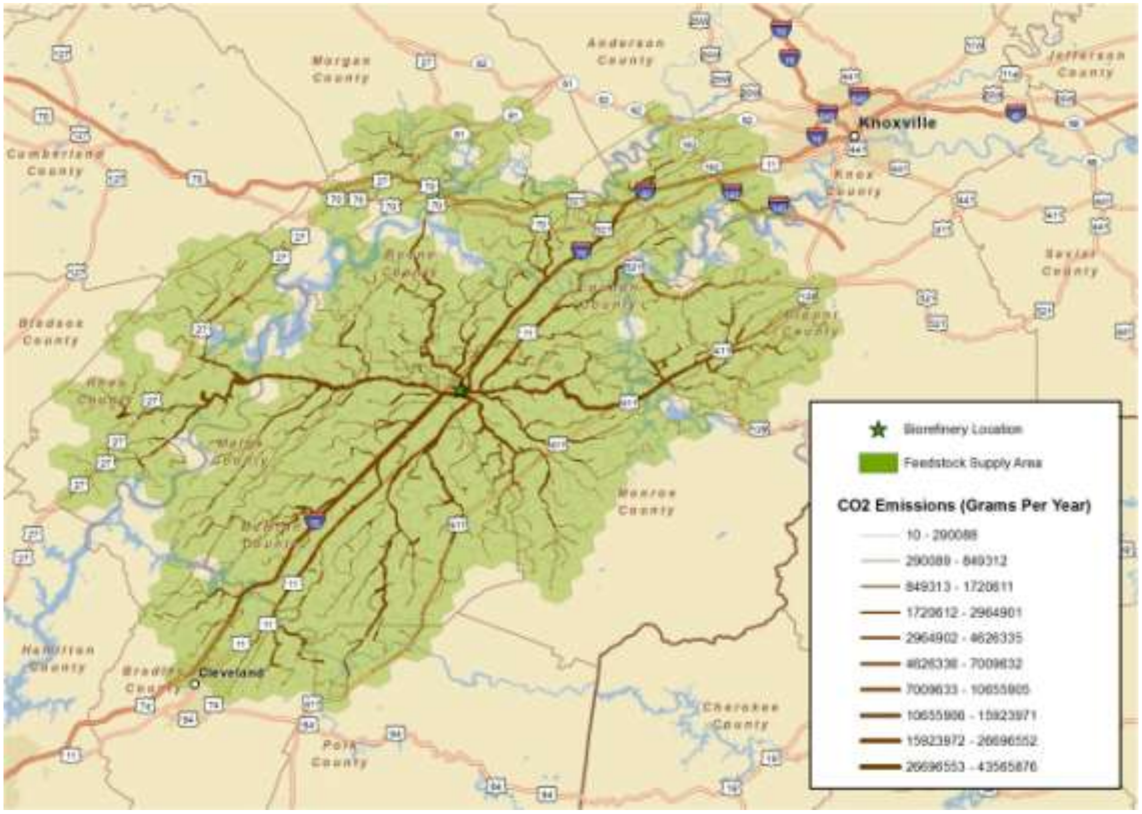

Figure 5 Annual CO_2 emission generated from truck traffic of switchgrass transportation

Aggregation of those emissions on the road networks by county can provide a better picture of the regional emission impact. Table 2 shows results of annual emissions for both estimated baseline emissions of all vehicle types and increased truck emissions from additional truck flows due to the logistic system for 13 counties in the study area for 2010. Overall Vehicle Miles Traveled (VMT) increased from additional truck flows are also included in Table 2. Total VMTs from additional truck flows of feedstock transportation were 3.7 million miles for all 13 counties. The estimated baseline level of NO_X, CO_2, PM_{10}, and $PM_{2.5}$ emissions from all vehicles in this region were about 29,000 tons, 8,023,000 tons, 2,100 tons and 1,800 tons, respectively. After adding the truck traffic of switchgrass shipment to the biorefinery on the border of Monroe and McMinn Counties, the emissions of NO_X, CO_2, PM_{10}, and $PM_{2.5}$ in the study area increased by 0.32%, 0.13%, 0.60%, and 0.71%, respectively, when comparing with the overall baseline emissions. In this logistic system, McMinn and Monroe Counties accounted for 65% of total VMT. In terms of the emission increases in level and growth rate, the most increased emissions were seen in Monroe County. NO_x, PM_{10}, and $PM_{2.5}$ emissions increased by 3.1%, 3.7%, and 3.8%, respectively. The second highest increase rate of emissions was found in Meigs County although the estimated increases in emissions were lower than in McMinn, Loudon, Rhea, and Roane Counties. The PM_{10}, and $PM_{2.5}$ increased by about 3.0% in Meigs County.

TABLE 2 Estimated Baseline Emissions and Additional Emissions from Increased Truck Flows from the Study for 2010

	Baseline emissions in tons/year				Additional emissions in tons/year					% increase			
County	**NOx**	**CO2**	**PM10**	**PM2.5**	**VMT**	**NOx**	**CO2**	**PM10**	**PM2.5**	**NOx**	**CO2**	**PM10**	**PM2.5**
Anderson	2,008.00	556,672.00	85.32	65.08	544	0.01	1.50	0.00	0.00	0.00	0.00	0.00	0.00
Blount	2,380.00	719,820.00	106.09	77.02	110,189	2.77	325.80	0.23	0.21	0.12	0.05	0.22	0.27
Bradley	2,546.00	699,182.00	106.45	81.45	83,918	2.19	262.30	0.19	0.17	0.09	0.04	0.18	0.21
Cumberland	2,674.00	620,155.00	99.65	84.71	508	0.01	1.60	0.00	0.00	0.00	0.00	0.00	0.00
Knox	10,578.00	3,201,748.00	482.44	346.79	28,810	0.73	65.90	0.06	0.06	0.01	0.00	0.01	0.02
Loudon	2,007.00	486,559.00	76.81	63.90	422,981	10.55	941.30	0.76	0.70	0.53	0.19	0.99	1.10
McMinn	2,119.00	521,841.00	82.15	67.53	1,085,156	28.17	2984.50	1.99	1.80	1.33	0.57	2.42	2.67
Meigs	212.00	59,885.00	8.46	6.59	214,611	5.70	589.20	0.42	0.38	2.69	0.98	4.97	5.77
Monroe	1,047.00	279,371.00	42.09	33.20	1,332,070	32.06	3945.40	2.74	2.42	3.06	1.41	6.51	7.29
Morgan	393.00	109,733.00	15.75	12.30	3,599	0.10	12.30	0.01	0.01	0.03	0.01	0.06	0.08
Polk	316.00	89,148.00	12.55	9.77	27,872	0.71	84.80	0.06	0.05	0.22	0.10	0.48	0.51
Rhea	554.00	163,037.00	23.44	17.52	216,230	5.54	632.20	0.45	0.40	1.00	0.39	1.92	2.28
Roane	2,051.00	515,525.00	81.16	65.71	190,876	5.27	597.50	0.43	0.38	0.26	0.12	0.53	0.58
Total	**28,885.00**	**8,022,676.00**	**1,222.36**	**931.57**	**3,717,364**	**94.00**	**10444.00**	**7.34**	**6.58**	**0.33**	**0.13**	**0.60**	**0.71**

CONCLUSIONS

Given the quickly evolving interests in the development of LCB biofuel in the U.S., the logistics involved in supplying LCB feedstocks to biorefineries has become a focus due to the demand for both quality and quantity of a somewhat bulky feedstock. In addition, the potential social and environmental impact of LCB feedstock transportation has also generated increasing attention given the potential for significant increases in traffic on the current road system. This study estimated the cost of producing, harvesting, storing, and transporting switchgrass along with associated emissions linked to hauling the feedstock using a commonly utilized feedstock harvest and logistic system in East Tennessee. Our results show that transportation costs account for nearly one-quarter of total cost under this large round bale system. Also, a 189.25 kl year^{-1} biorefinery, demanding about 50,000 truckloads of switchgrass feedstock annually, could potentially cause an additional 100,000 truck trips of large round bale switchgrass per year on the various roadways that connect production fields to the biorefinery.

Additional truck traffic due to switchgrass feedstock logistics also added more emissions in the study region. Based on the estimated additional 3.7 million VMTs of feedstock transportation within the 13 counties, the preliminary estimate using EPA's MOVES2010a model suggested that the emissions of NO_X, CO_2, PM_{10}, and $PM_{2.5}$ in the study area increased by 0.32%, 0.13%, 0.60%, and 0.71%, respectively, when comparing with the overall baseline emissions. As expected, the increases of all emissions in those counties adjacent to the biorefinery were much higher than the regional average. In terms of the emission increases in level and growth rate, the most increased emissions were found in Monroe County where the biorefinery was located. The second highest increase rate of emissions was found in the Meigs County; the emission growth rate was nearly 3.0% compared to the baseline level.

This case study illustrates the environmental impact of the transportation of feedstock for delivery at a biorefinery may generate. The results will likely change based on different logistic and harvest systems. Also, the capacity of the biorefinery will affect the volume of traffic, hence emissions. The analytical framework developed in this study can be applied to evaluate various feedstock logistic and harvest systems and compare their emissions and plant gate costs associated with each system. The knowledge of both the economic cost and emission impact can help the nation or state develop a sustainable LCB-based biofuel industry.

REFERENCES

Brass, L. East Tennessee Farmers' First Switchgrass; Harvest Ready to Turn Into Biofuel. *Checkbiotech*, January 10, 2011. http://bioenergy.checkbiotech.org/news/east_tenn_farmers_first_switchgrass_harvest_ready_turn_biofuel. Accessed March 9, 2011.

English, B. C., D. de La Torre Ugarte, K. Jensen, C. Hellwinckel, J. Menard, B. Wilson, R. Roberts, and M. Walsh. *25% Renewable Energy for the United States By 2025: Agricultural and Economic Impacts: Report to the 25x25 Energy Work Group*. Biobased Energy Analysis Group, Department of Agricultural Economics, The University of Tennessee, 2006.

Gao, Y. Evaluation of Pre-processing and Storage Options in Biomass Supply Logistics: A Case Study in East Tennessee. M.S. Thesis. The University of Tennessee, Knoxville, 2011.

Goodman, J. The Cellulosic Ethanol Boom That Never Happened. *Stateline*, March 7, 2011. http://www.stateline.org/live/details/story?contentId=556119. Accessed March 8, 2011.

Kumar, A., S. Sokhansanj, and P.C. Flynn. Development of a Multicriteria Assessment Model for Ranking Biomass Feedstock Collection and Transportation Systems. *Applied Biochemistry and Biotechnology*, Vol. 129, 2006, pp 71–87.

Larson, J. A., T. Yu, B. C. English, D.F. Mooney, and C. Wang. Cost Evaluation of Alternative Switchgrass Producing, Harvesting, Storing, and Transporting Systems and their Logistics in the Southeastern US. *Agricultural Finance Review*, Vol. 70, No. 2, 2010, pp. 184-200.

Osborne, S. *Energy in 2020: Assessing the Economic Effects of Commercialization of Cellulosic Ethanol*. U.S. Department of Commerce, Washington D.C., November, 2007.

Thornley, P. Airborne Emissions from Biomass Based Power Generation Systems. *Environmental Research Letters*, Vol. 3, No. 1, 2008, pp 1-6.

U.S. Environmental Protection Agency. *National Emissions Inventory Data & Documentation*. 2005. http://www.epa.gov/ttn/chief/net/2005inventory.html. Accessed February 13, 2010.

U.S. Environmental Protection Agency. *Official Release of the MOVES2010 Motor Vehicle Emissions Model for Emissions Inventories in SIPs and Transportation Conformity*, Official Release of the U.S. FR Doc. 2010-4312. *http://www.gpo.gov/fdsys/pkg/FR-2010-03-02/html/2010-4312.htm*. Assessed Oct. 15, 2010.

U.S. Code, TITLE 42, Chapter 85-Air Pollution Prevention and Control. http://www.gpoaccess.gov/uscode/browse.html. Assessed January 18, 2011.

Wang, C. Economic Analysis of Delivering Switchgrass to a Biorefinery from both the Farmers' and Processor's Perspectives. M.S. Thesis. The University of Tennessee, Knoxville, 2009.

Wang, M., C. Saricks, and D. Santini. Effects of Fuel Ethanol Use on Fuel-cycle Energy and Greenhouse Gas Emissions. U.S. Department of Energy, Argonne National Laboratory, Center for Transportation Research, Argonne, IL, 1999.

Wilson, B. S. Modeling Cellulosic Ethanol Plant Location Using GIS. M.S. Thesis. The University of Tennessee, Knoxville, 2009.

Wright, L. *Historical Perspective on How and Why Switchgrass was Selected as a "Model" High-Potential Energy Crop*. Publication ORNL/TM-2007/109. Oak Ridge National Laboratory, Oak Ridge, TN, 2007.