Analyzing the Impact of Intermodal Facilities to the Design and Management of Biofuels Supply Chain

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ABSTRACT

This paper analyzes the impact that an intermodal facility has on location and transportation decisions for biofuel production plants. Location decisions impact the management of the in-bound and out-bound logistics of a plant. We model this supply chain design and management problem as a mixed integer program. Input data for this model are location of intermodal facilities and available transportation modes; cost and cargo capacity for each transportation

INTRODUCTION

This work is motivated by the continued growth of interest in developing cleaner, renewable energy sources. Bioenergy is such a source of energy that can help the United States to reduce its dependency on fossil fuels (*1*). Bioenergy is produced from biomass feedstocks, which are plant-derived materials including animal manure. According to the nationwide renewable fuels standard, the supply of renewable energy is expected to increase from 4 billion gallons in 2006 to 7.5 billion gallons by 2012. As a result, we anticipate that a number of biorefineries will open in the near future.

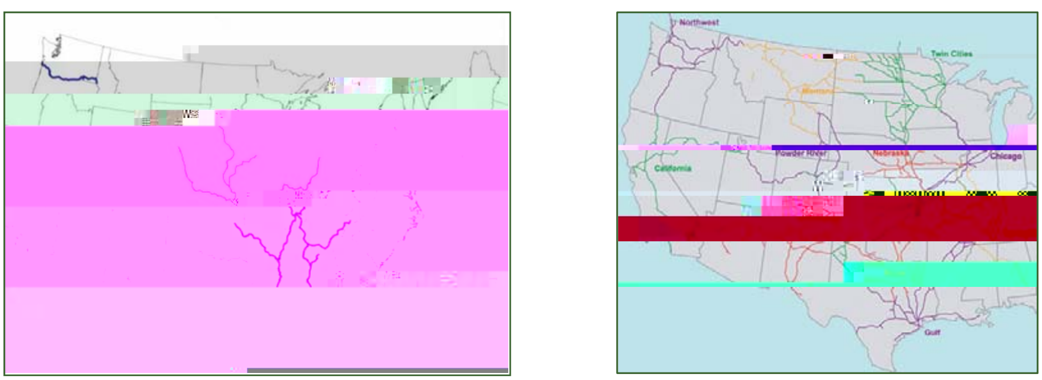
Biorefinery location decisions impact and are impacted by transportation and other supply chain related decisions. Due to the particular nature of biomass (biomass is bulky and difficult to transport), biorefinery logistics costs are high. For example, it is estimated that 20-40% of the total cost of ethanol is due to biomass supply, and 90% of these costs are due to the logistics of biomass delivery. This is the reason why 76% of ethanol is currently produced in rest is purchased from corn elevators located in the Midwest. To make use of the increased supply of corn and woody biomass which is abounding in the state, we anticipate that other plants will open in the near future. Therefore, identifying potential locations for these plants and designing cost efficient in-bound and out-bound distribution chains for biorefineries is very important. The availability of well-designed supply chains will aid in attracting investors to Mississippi, potentially having a positively impact on the economy of Mississippi, and providing new job opportunities for rural Mississippians.

BACKGROUND

Biomass-to-Biorefinery Supply Chain

The in-bound and out-bound parts of the supply chain of a biorefinery are different from those of traditional refineries that use crude oil. Biomass is harvested at farms, collected at facilities near the farms and then shipped to biorefineries using trucks. Ethanol is shipped by truck, barge or rail to blending facilities. Trucks are then used to ship ethanol blends such as E-10 (gasoline blended with 10% ethanol) and E-85 to gasoline retail outlets.

Different transportation modes can be used to ship ethanol. The same is true for DDGS and biomass. The choice of a transportation mode depends on the distance between origin-destination of a shipment, and the proximity to intermodal facilities (such as rail terminals, sea ports, in-land ports, etc). Due to the high cost of transporting biomass, 76% of ethanol produced in the USA comes from small-sized biorefineries located in four major corn producing states in the Midwest. Collecting and transporting biomass within a 50 mile radius is the economic threshold that has been used in the literature. Mahmudi and Flynn (*5*) show that the shipping distance (for wood chips) beyond which rail is more economical than truck is 145km (90miles). The increased demand for ethanol and economies of scale (in utilization of byproducts and distillation of ethanol) favor larger scale facilities. Larger biorefineries imply a larger number of biomass suppliers, longer transportation distances, and higher shipping volumes.



(a) Agriculture Significant Waterways (b) BNSF Rail Map

FIGURE 1 Agriculture significant distribution corridors.

The grain handling infrastructure in the United States has been built over the years to reliably and effilt o-10.58Rsportati efastrut i%o8(i)l(a) i%o8(i)l(a) i%.4(ndlarts 95 -1agrut)7. flTD-(i agriculturally significant waterways (Figure 1). Destination plants that have access to in-land ports and sea ports can ship corn from these Sates using barge. Barge provides large transportation capacity at a low price. Mississippi has access to the Mississippi River in the west and Tombigbee River in the east. The strategic location of the state is clearly an advantage for ethanol producers.

Railways are also major carriers of corn. For example, Burlington Northern Santa Fe (BNSF) Railway, whose rail tracks span the western part of the United States, is a major carrier for corn and other agricultural products. Rail cars are used to ship ethanol, corn and DDGS from the Midwest to the east and west coasts of the United States.

An intermodal facility is where various transportation modes meet. At an intermodal facility loads of commodities are transshipped from one mode to another such as from trucks to trains, and barges. Considering the impact of transportation costs on the production cost of biofuels, one can see why decisions on the location of a biofuel destination plant are impacted by the location of intermodal facilities. When located near to an intermodal facility, biorefineries can take advantage of affordable transportation modes and potentially reduce their transportation costs. For example, the first ethanol production plant in Mississippi is located near the port of Vicksburg. The selection of this site was motivated by the affordable cost of shipping corn by barge from the Midw

FIGURE 3 Network representation of the fiofuel supply chain.

The decision variables are: x_{ij}^k which represents the flow of commodity k on arc $(i,j)\in A$. y_{il}^1 is a binary variable that takes the value 1 if a biorefinery of size l ($l\in S^1$) is located at node i ($i\in N^B$), and takes the value 0 otherwise; y_{il}^2 is a binary variable that takes the value 1 if the collection facility of size l ($l\in S^2$) located at node i ($i\in N^C$) is being used, and takes the value 0 otherwise.

Other *notations* used are: c_{ij}^k represents the cost of flowing commodity k on arc (i,j); ψ_{il} is the amortized annual cost of constructing and operating a biorefinery of size l at node i; SB_l is the storage capacity of a biorefinery of size l; SC_l is the storage capacity of a collection facility of size l; CP_l is the production capacity of a biorefinery of size l; $\beta_{k\kappa}$ is the conversion rate of biomass k to biofuel κ; λ_i^k is the amount of biomass type k available at harvesting site i. This amount is a function of the total land available, production yield, and the proportion of biomass that can be used to produce biofuel. D_i^k is the demand for biofuel k of customer $i\in N^{CS}$. M

$$\sum_{k\in K}\sum_{j\in N^F} x_{ij}^k - x_{il}^k + x_{fi}^k \le \sum_{l\in S^1} CP_l y_{il}^1 \qquad i\in N_t^B, l\in N_{t+1}^B, f\in N_{t-1}^B, t=1,\ldots,T \qquad (7)$$

$$\sum_{k\in K}\sum_{i\in N^H} x_{ij}^k \le \sum_{l\in S^2} SC_l y_{jl}^2 \qquad j\in N^C \qquad (8)$$

$$\sum_{k\in K} x_{ij}^k - Mz_{ij}^\delta \le 0 \qquad (i,j)\in A^T; \delta\in\Delta \qquad (9)$$

$$\sum_{k\in K} x_{ij}^k - U^\delta r_{ij}^\delta \le 0 \qquad (i,j)\in A^T; \delta\in\Delta \qquad (10)$$

$$x \ge 0 \qquad (11)$$

$$y, z \in \{0,1\} \qquad (12)$$

$$r \in Z^+ \qquad (13)$$

The objective here is to identify locations for biorefineries, transportation modes to use, transportation schedule, and bi0fuel pa odrTD71 Tf125.96 480.c77.5lA8054eek7A8e54aenti a v a i l considered. In addition to the harvesting sites located in Mississippi, we consider three additional sites located in the Midwest. One of these sites is located in Illinois, one in Ohio, and one in Iowa. Corn from the Midwest is shipped to Mississippi by train or barge.

Each county in Mississippi is considered to be a candidate location for collection facilities and biorefineries. We identified 15 blenders located in Missis

Where, \$1127.8 is the fixed cost of a railcar (A^{δ}), and \$2.1738 is charged per mile traveled (c_{ij}^{k}). The value of R^2 for this regression is 96.5% and the *p*-value for the independent variable is 1.45*E*-71. That means distance is a significant factor when estimating rail transportation costs.

The regression equations for corn under option (b) is y=2.1738x+1827.81. The value of R^2 for this regression is 96.5% and the *p*-value for the independent variable is 1.45*E*-71.

The regression equations for ethanol under option (a) is y=1.15x+3444.86. The value of R^2 for this regression is 75% and the *p*-value for the independent variable is 1.03*E*-12.

The regression equations for ethanol under option (b) is y=1.15x+2044.86. The value of R^2 for this regression is 96.5% and the *p*-value for the independent variable is 1.45*E*-71.

Other input data used in this paper (such as processing costs, conversion rates, etc) are the same with Eksioglu et al. (*24*).

Computation Result

Using the data collected, we generate a base scenario for testing our model. Next, we change the values of some input data one at a time to generate additional test problems. We use CPLEX 9.0 callable libraries to solve the MIP problems for each scenario we test. CPLEX is a commercial LP/MIP solver.

In our experiments we consider that the total amount of corn available in Mississippi is 1,316,000 dry tons per year. This amount was calculated based on corn production in the state in the last 5 years. Considering that 10% of the corn produced is used for ethanol, and conversion rate of corn to ethanol is 119.5 gal/dry ton, we estimate that the maximum annual ethanol from corn production in Mississippi is 15.7MGY. Therefore, it is expected that biorefineries with a capacity of 10MGY will mainly use corn which is available in the state. For larger capacities, corn will be shipped from the Midwest. We expect that location decisions for biorefineries with a (assuming 0% increase in transportation costs) total biomass transportation costs increase, and investment costs decrease. The increase in transportation costs is due to the fact that biomass needed is shipped from sites located further away (Midwest). The decrease in investment costs is due to economies of scale in production.

TABLE 2 Barge: Distribution of the Delivery Cost of Ethanol

Costs	Annual Ethanol Production (MGY)				
	Delivery Cost of Ethanol (in $/gal)				
	10	20	30	40	60
Total	3.060	2.793	2.703	2.582	2.510
Biomass Trans.	0.126	0.138	0.145	0.150	0.155
Ethanol Trans.	0.217	0.217	0.217	0.217	0.217
Inventory of Biomass	0.415	0.415	0.415	0.415	0.415
Investment	1.403	1.126	1.029	0.904	0.826
Harvesting	0.651	0.651	0.651	0.651	0.651
Processing	0.245	0.245	0.245	0.245	0.245

TABLE 3 Barge: Distribution of Shipments between Midwest and Mississippi

(a) since corn in Midwest is harvested in a different period than in Mississippi, receiving shipments from the Midwest during the non-harvesting months reduces biomass inventories, and as a consequence inventory holding costs; (b) barge is an inexpensive shipment mode for shipping corn in long distances.

Considering these findings we wanted to see what would happen if barge shipments were not available. Mississippi is strategically located on the Agricultural Significant Waterways (see Figure 1). It is interesting to see what happens if this option was not available, as it is the case with a number of other states. Results in Tables 4 assume that rail is used to ship corn from the Midwest. When barge is not available, the delivery cost of ethanol slightly increases. This increase is mainly due to transportation costs. In the case when the annual production of ethanol is 10MGY, corn is supplied from Mississippi only. This is due to the fact that rail shipments are more expensive compared to barge. For the experiments presented in Table 4, the location selected for the biorefinery is Warren County since there is a rail ramp in this county.

TABLE 4 Rail: Distribution of Shipments between Midwest and Mississippi

Annual Ethanol Production (MGY)	Tr. C 0%	Midwest	MS	Tr. C 150%	Midwest	MS
	Ethanol (in $/gal)			Ethanol (in $/gal)		
10	3.09	0.00%	100.00%	3.63	0.00%	100.00%
20	2.90	46.63%	53.37%	3.48	38.31%	61.69%
30	2.83	63.93%	36.07%	3.45	58.87%	41.13%
40	2.72	70.85%	29.15%	3.36	69.15%	30.85%
60	2.66	78.89%	21.11%	3.31	78.85%	21.15%

TABLE 5 Shipment Distribution

Gal/dt	Ethanol Deliv. Cost (in $/gal)	Shipment Distribution				
		Midwest	MS	Truck	Rail	Barge
120	2.49	75.22%	24.78%	24.70%	0.09%	75.21%
115	2.55	76.38%	23.62%	23.61%	0.03%	76.37%
110	2.61	77.31%	22.69%	22.73%	0.00%	77.27%
105	2.69	78.47%	21.53%	21.43%	0.12%	78.45%
100	2.76	79.39%	20.61%	20.64%	0.00%	79.36%
95	2.84	80.32%	19.68%	19.62%	0.07%	80.30%
90	2.95	81.48%	18.52%	18.47%	0.07%	81.46%

Table 5 presents the break-even of ethanol delivery costs for different values of conversion rate. This table also presents the distribution of shipments between Midwest and Mississippi, and among different transportation modes as the conversion rate changes from 120 to 90 gallons/dry ton. The annual production of ethanol is assumed 40MGY. The increase in the delivery cost of ethanol (as the conversion rate decreases) is mainly due to the increase in transportation and processing costs. As conversion rate decreases, larger amount of biomass

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PROJECT DISSEMINATION

No awards have been received for the work completed in this project. For this project we received $13,499 as matching funds from the Office of Research and Economic Development at MSU.

So far, we have received additional funding ($77,621) from NCIT for the period May 2009 – May 2010. These funds will be used to continue the research started in this project. We are working with Sumesh Arora, the Director of Strategic Biomass Initiative at Mississippi Technology Alliances (MTA), to have the tools built in this model used by potential biofuel production plants locating in Mississippi. In collaboration with Sumesh, we completed a proposal which we submitted to MTA. The work of the proposal submitted to MTA is an extension to the currently completed project.

The research completed in this project was presented at 2009 Industrial Engineering Annual Meeting. The paper submitted for this presentation was published in their proceedings. We also have submitted a paper for the 2010 Transportation Research Board 89th Annual Meeting to be held in Washington, D.C. January 10-14, 2010. The paper if accepted will be published at the Transportation Research Record, a journal of Transportation Research Board. The graduate student working on this project gave 2 poster presentations of this work.

Ekşioğlu, S.D., S. Zhang, S. Li "Analyzing the Impact of Intermodal Facilities to the Design of the Supply Chains for Biorefineries," IIE Annual Conference, Miami, FL, May 2009.

S. Zhang, S. Li, S. D. Ekşioğlu "Analyzing the Impact of Intermodal Facilities to the Design and Management of Biofuels Supply Chain." 1st Transportation Workshop, Feb. 6, 2009, Mississippi State, MS.

S. Li , S. Zhang, S. D. Ekşioğlu "Analyzing the Impact of Intermodal Facilities to the Design of Supply Chains for Biorefineries," 2009 MSU Biofuels Conference, Aug. 6-7, Jackson, MS.

1. Would you consider your project to be basic research, advanced research, or applied research?	Applied Research
2. Number of transportation research reports/papers published	1 conference proceeding published 1 journal paper submitted
3. Number of transportation research papers presented at academic/professional meetings	1 research paper presentation 2 poster presentations

	Undergraduate	**Graduate**
4. Number of students participating in transportation research projects		2

5. Number of transportation seminars, symposia, distance learning classes, etc. conducted for transportation professionals	
6. Number of transportation professionals participating in those events	

In December 2008, Dr. Jin and Dr. Eksioglu gave a workshop titled "Logistics and Supply Chain Management." This was a 2 day workshop which was delivered to a group of 14 professionals from companies located in Mississippi.

In February 6, 2009, Transportation Working Group held the "1st Transportation Workshop." There were 22 poster presentations in this workshop. We had a number of faculty and students from MSU participating and attending the workshop.

During Aug. 2008 to May 2009, the Transportation Working Group organized six transportation related seminars. Each seminar was attended by 25-30 students and faculty. Information about these seminars can be found in the following website:
http://www.bagley.msstate.edu/research/workinggroups/transportation/index.php