Economics of Sourcing Cellulosic Feedstock for Energy Production

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Abstract

This study investigates the economics of supplying wheat straw and corn stover within 100 mile radius of a potential new biorefinery in southeast North Dakota. In particular, straw and stover total delivery costs, potential straw and stover supply sites and least cost transportation routes are identified using a linear programming transport model and a GIS (Geographic Information Systems) mapping system. We show that USDA/NRCS (Natural Resources Conservation Service) future crop residue removal rate policies will be important for determining whether it is economically viable to harvest crop residues as potential feedstock for energy generation. Increase in residue removal rates narrow the size of residue supply areas and consequently result in lowering total transportation costs. There is an economic tradeoff between residue collection density and distance from the biorefinery. Most wheat residues are highly concentrated in the north, some distance from the biorefinery. Relying solely on wheat straw for supply needs require longer transportation distances which increases total cost. Using a combination of wheat and corn residues lowers total transportation costs. Since most wheat/corn residues are densely concentrated in north/south, regional highways would likely be the routes used often to transport the residues, as compared to interstate highways. Increased traffic volumes due to the hauling of crop residues would require additional investment in improving road conditions.

1. Introduction

The purpose of this research is to evaluate the economics of sourcing crop residues such as wheat straw and corn stover in southeast North Dakota where a cellulosic biorefinery is planned to be constructed. Numerous studies (Sokhansanj and Turhollow 2002; Gallagher et al. 2003; Perlack and Turhollow 2003, Petrolia 2008, and Turhollow and Sokhansanj 2007) have analyzed the economics of stover supply for biofuel production. These studies focused on estimating costs of harvesting stover as whole. In this paper, we look into the total delivery costs which consist of on-farm collection, farm-to-storage transport, storage, and storage-to-plant transport costs and identify potential wheat straw and corn stover supply sites and routes using a linear programming transport model and a GIS mapping system.

To achieve our goal, geographic area for feedstock supply is described in section 2. Potential constraints to crop residue removal are identified in section 3. Section 4 describes the methodology needed to determine the optimal hauling cost and location of supply sites. Section 5 describes the assumptions and data used in our study. Empirical results are interpreted in section 6 and potential locations of supply sites and routes are mapped in section 7. Finally, section 8 presents overall summary for our study.

2. Geographic Area for Potential Crop Residue Collection within 100-Mile Radius of Biorefinery

The geographic area within a 100 miles radius from the biorefinery (our focal point) is defined utilizing GIS software (Fig 2.1). The counties in this area are located in three states: North Dakota, South Dakota and Minnesota. Twenty eight counties are in southeast and northeast regions of North Dakota, accounting for 90% of the total area of interest. Sixteen of these counties are fully enclosed in the area of interest. Four additional counties are located in northwest Minnesota, contributing 4% to the total area. South Dakota contributes 6% to the total area of interest. For each county, the percent of contribution to the 100-miles radius area is calculated using GIS utilities.

Table 2.1 ranks each county in the study region based on density of wheat straw available. It also shows the linear distance of each county to the biorefinery. To minimize total wheat straw collection and hauling costs, residue should be sourced from nearby counties with the greatest density. Suppose a goal is to minimize on-farm bale collection cost by restricting the density of wheat acres in each county to be 15% or above and to minimize hauling cost by restricting straight line distance from storage site in each county to the biorefinery to no more than 70 miles. With these restrictions, Table 2.1 suggests that only a few counties have the potential of supplying wheat straw: Wells, Nelson, Foster, Steele, Griggs, Cass and Barnes. Similar restrictions can be imposed on corn stover supply. Potential supplies for corn stover would likely come from nearby counties with relatively high density of corn acres, such as Barnes, Cass, Ransom, Steele, Dickey and LaMoure (data are not reported but available upon request). As indicated, geographically, density or concentration of wheat straw/corn stover is higher in the northern/southern part of the biorefinery. Greater density of wheat/corn acres means more straw/stover can be supplied with lower collection cost and more assurance. But the drawback is that more distance would have to be traveled to collect straw/stover in the north/south which would result in an increase in transport cost. Hence, the two criteria of density and distance represent an economic tradeoff. The optimal selection will depend on the relative costs of each characteristic. Using a linear programming transport model along with GIS map, we examine the economic tradeoff between density and distance in this study.

Figure 2.1 Geographic Area within 100-mile Radius of Biorefinery in Southeast North Dakota

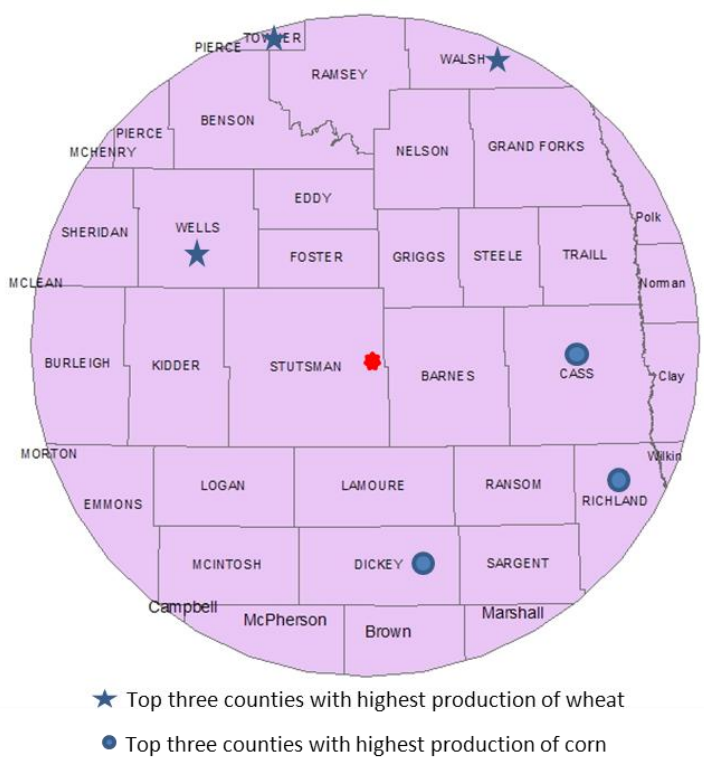


Table 2.1 Wheat Straw Supply Ranking for Top 24 Counties in North Dakota

Supply Ranking Based on Density	County	Density (%)	Straight Line Distance* from Biorefinery (mile)
1	Towner	31.37	96
2	Walsh	27.89	91
3	Wells	25.11	62
4	Norman (MN)	23.75	91
5	Polk	22.94	93
6	Grand Forks	22.13	79
7	Pierce	20.21	92
8	Nelson	19.47	61
9	Foster	18.34	30
10	Steele	18.24	48
11	Benson	17.59	77
12	Ramsey	17.31	81
13	Traill	17.19	72
14	Sherdian	16.29	88
15	Griggs	15.96	31
16	Cass	15.70	64
17	Barnes	15.48	26
18	Emmons	14.95	88
19	McHenry	14.35	97
20	McIntosh	14.19	77
21	Eddy	12.39	48
22	Logan	12.01	61
23	Stutsman	10.70	20
24	Richland	10.64	87

* Based on the center of each county within 100 mile radius.

3. Potential Constraints to Crop Residue Removal

Potential constraints to residue collection are identified and most notable ones are use of rotary combines, tenant/landowner control, and Natural Resources Conservation Service (NRCS) environmental constraints.

Rotary Combines

Combines used to harvest wheat are of two different types, conventional and rotary. Manufactures of the former are John Deere while the latter are CNH and Caterpillar. Rotary combines have the advantage of faster grain harvesting and gentler seed handling. However rotary combines require more horsepower to propel the crop over a larger separation area. When straw passes through a rotary combine, it ends up coming out of the machine in very small pieces. Farmers in our focus group meeting (Appendix I) even described it as dust. This poses a challenge to straw gathering as it cannot be raked or picked up with a baler. While actual market share data are not publically available, both machines are equally popular but the current trend is from conventional to rotary. The impact of nearly one half of combines being rotary on wheat straw feasibility is that it reduces potential straw availability by up to half. While growth of a straw market may entice producers to switch from rotary to conventional, the hurdle would be difficult to overcome initially.

Tenant/Landowner Control

North Dakota's Farm Business Management records show that among the farms that participate in the association, 27 percent of farmland is owned by the operator, 66 percent is cash rented and only 7 percent is share rented. Farmers who rent land have a keen interest in biomass produced on acreage, just as they do in the grain that is produced. Since they often supply most inputs, labor, and machinery services, renters have an economic investment in output that accrues. However, landowners could also make a claim in biomass that is produced. Historically, biomass produced on land that is leased to tenants has not been collected. Instead, biomass produced was left on the soil providing valuable protection against wind and water erosion. Overtime, decomposing biomass builds soil organic matter and overall soil health. Consequently, residual biomass was a portion of the return expected from the rental arrangement. North Dakota law states that tenants own production that accrues over the rental period, which broadly includes crop residues. This line of reasoning is consistent with past practices which allow tenants to remove straw for feed and bedding. However, landowners also are protected. The law generally prohibits a tenant from damaging the land. This could prohibit a tenant from removing tremendous amount of crop residues that the land is damaged by increased erosion and decreased soil organic matter. Hence, the amount of residue a tenant can remove may be limited.

Natural Resources Conservation Service (NRCS) Environmental Constraints

Most farms in the study region contain some highly erodible land which requires a NRCS conservation plan in order for producers to receive farm program benefits. To understand provisions NRCS might apply to wheat straw removal across varying topographies in the study region, we held a meeting with North Dakota state NRCS staff. Due to the concerns with soil erosion and fertility loss, NRCS staff suggested that the amount of straw/stover that can be removed from the field can be very limited. Even the assumption of 25% residue removal rate is overstated. Although NRCS is still mindful of highly erodible land characteristics and the potential for wind/water erosion, its primary focus now is on carbon. The NRCS's overall policy is to recommend that 2-3,000 lbs of organic matter remain in or on the soil after harvest, regardless of crop, for carbon maintenance. However if low residue crops like soybeans or sugarbeets are planted in rotation with wheat and do not leave enough carbon on soil, their annual deficit must be made up with wheat straw from rotational crops in succeeding years. As a result the availability of wheat straw is reduced. One way that producers could harvest crop residues and yet meet NRCS guidelines would be to plant a cover crop as suggested by Hans Kandel, NDSU plant scientist. Currently a research trial has underway to evaluate this potential.

4. Methodology

Transport Model for Individual Wheat Straw and Corn Stover

The following cost minimization transport model considers hauling either 100% wheat straw or 100% corn stover from a number of farms or supply points located throughout North Dakota to the biorefinery, the demand point. The objective function (equation 1.1) depicts total cost minimization across all possible shipment routes for either straw or stover.

$$Minimize \quad \sum_i \sum_j C_{ij} X_{ij} \qquad 1.1$$

$$subject\ to \quad \sum_i X_{ij} \geq D_j \quad for\ all\ j \qquad 1.2$$

$$\sum_j X_{ij} \leq S_i \quad for\ all\ i \qquad 1.3$$

$$X_{ij} \geq 0 \qquad for\ all\ i\ and\ j$$

In specifying the model, information about the supply points are denoted as i[1], and the demand point is denoted as j=1 (since we have only one demand location). Parameter C_{ij} denotes the cost of delivering one ton of wheat straw/corn stover from supply point i to the demand point j. The quantity of wheat straw/corn stover hauled from each supply point to the demand point will be designated as X_{ij}. Parameter D_j denotes the total quantity of either 100% wheat straw or 100% corn stover demanded at the demand point j. The demand constraint (equation 1.2) requires the sum of incoming shipments to the demand point j from all possible supply points i to be greater than D_j. Parameter S_i denotes the quantity of wheat straw/corn stover available at supply point i. The supply constraint (equation 1.3) requires the sum of outgoing shipments from i^{th} supply

[1] For n supply locations, i=1,..,n

point to the demand point j to be no greater than S_i. Implicitly, the model assumes a perfectly competitive wheat straw/corn stover market and the suppliers of wheat straw/corn stover cannot charge the demander more than the market price plus the shipping cost. In other words, the differences in market prices of wheat straw/corn stover would only reflect the differences in shipping costs between locations.

Transport Model for a Combination of Wheat Straw and Corn Stover

This model involves hauling a combination wheat straw and corn stover to the biorefinery. For example, the hauling combination could be 50% wheat straw and 50% corn stover or 30% wheat straw and 70% corn stover. The cost minimization problem can be modified from above and written as:

$$Minimize \quad \sum_i \sum_j e_{ij} Y_{ij} + \sum_i \sum_j h_{ij} Z_{ij} \qquad (2.1)$$

$$subject\ to \quad \sum_i Y_{ij} \geq D_{j1} \ \ for\ all\ j \qquad (2.2)$$

$$\sum_i Z_{ij} \geq D_{j2} \ \ for\ all\ j \qquad (2.3)$$

$$\sum_j Y_{ij} \leq S_{i1} \ \ for\ all\ i \qquad (2.4)$$

$$\sum_j Z_{ij} \leq S_{i2} \ \ for\ all\ i \qquad (2.5)$$

$$Y_{ij} \geq 0\ ; \ \ Z_{ij} \geq 0 \quad for\ all\ i\ and\ j$$

The objective function (equation 2.1) depicts total cost minimization across all possible shipment routes for a combination of both straw and stover. Y_{ij} (Z_{ij}) is denoted as the quantity of wheat straw (corn stover) hauled from each supply point i to the demand point j. The parameters, e_{ij} and h_{ij}, are costs of hauling each ton of wheat straw and corn stover from supply point i to the demand point j. D_{j1} and D_{j2} are quantities of wheat straw and corn stover demanded at the demand point j. S_{i1} and S_{i2} are quantities of wheat straw and corn stover available at each supply point i. Equations 2.1 and 2.2 are the demand constraints and Equations 2.4 and 2.5 are the supply constraints for straw and stover respectively.

To estimate above model, the data required are total hauling costs from each supply point to the demand point and the availability of straw and stover in each supply location within the 100-mile radius of biorefinery. Total hauling costs are estimated using the method described below. The amount of straw and stover available in each supply location or storage site is generated using GIS application.

Field to Storage Distance

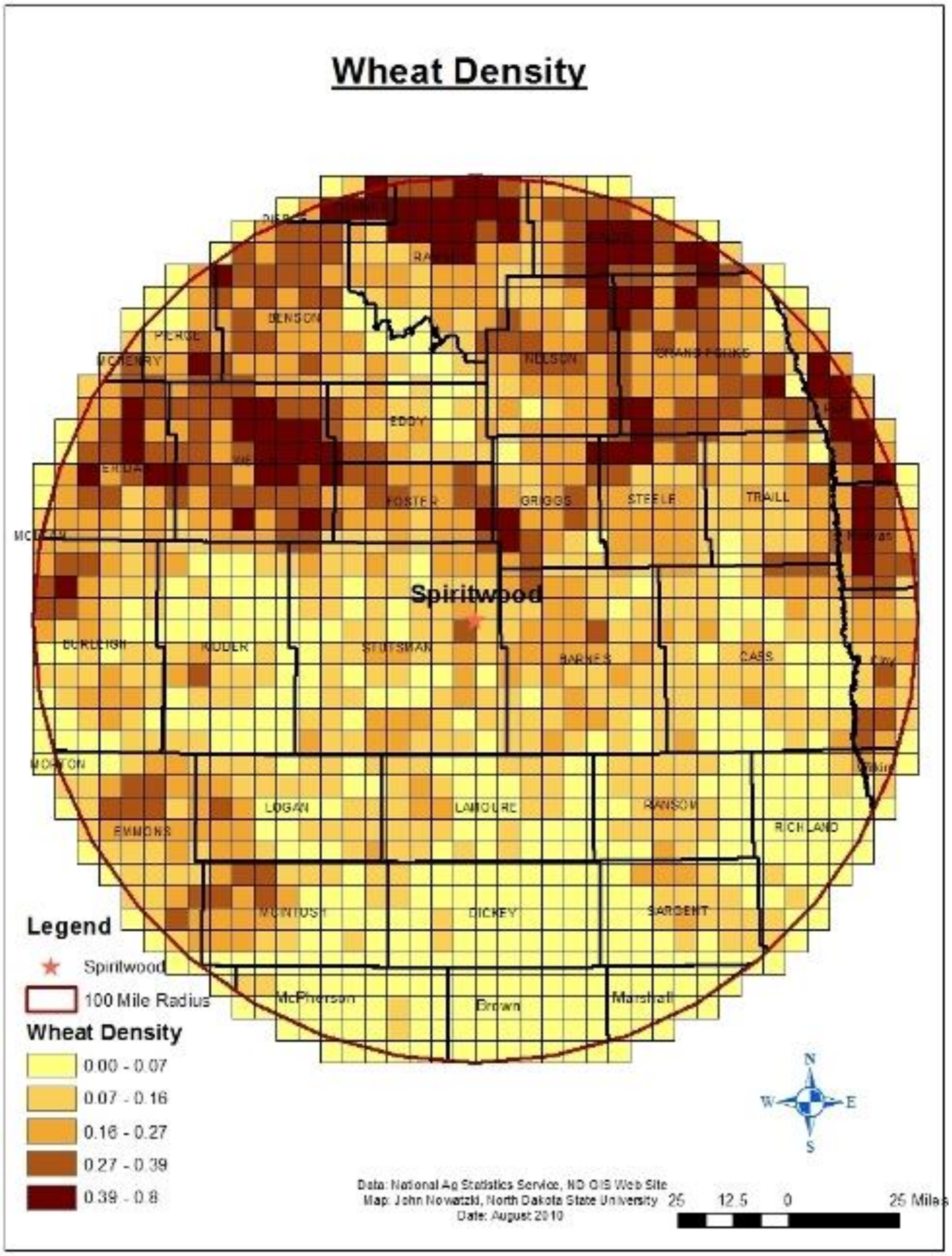
As indicated, the above transport models minimize total hauling costs of crop residue delivery to the plant. It determines optimal storage or supply locations based on hauling distance, density and yield of residue, and the size of storage. The model begins with calculation of distance. Given a square grid system of roads as described in French (1960) and McCarl et al. (2000), the average distance (D) from field to storage can be estimated as:

$$D = 0.4714 * \sqrt{\frac{M}{640 * Den * Yld}} \qquad (3)$$

where *M* is defined as fixed amount of residue supplies (in ton) from each 5-mile square grid (shown in Fig 4.1 for the case of wheat straw). The factor "640" represents the number of acres in a square mile. *Den* is denoted as the density of residue acres. It can be estimated by dividing total harvested acres of crop residue by total land acres in a given area. *Yld* is defined as a harvestable residue yield (in ton per acre).

For the purpose of finding optimal storage sites using our model, it is assumed that in the beginning a potential residue storage site is located at the center of each small 5-mile square grid within 100 mile radius (Fig 4.1) and that each site or grid is required to supply *M* tons of residue. We assume that the biorefinery requires a total of 480,000 tons of residue (either wheat straw or corn stover or a combination of both) supply annually. Hypothetically, Fig 4.1 shows that there are a total of 1,324 5-mile square grids or storage sites within 100 mile radius. If each storage site can supply equal amount of residue, this would suggest 363 tons per site. The number of storage sites is then reduced to an optimal level using our transport model. Equation (3) takes into account residue density and yield for each grid when calculating field to storage hauling distance (D). The hauling distance from field to storage with a 30% road winding factor is estimated for each storage site in each grid using equation (3).

Figure 4.1 Concentration of Wheat Straw within 100 Mile Radius of Biorefinery



Storage to Plant Distance

Using GIS, straight line distance from the center of each 5-mile square grid to the biorefinery is estimated. Straight line distance is converted to actual road distance using a road winding factor of 30%.

5. Description of the Assumptions and Data

Following the insights provided by farmers during our focus group meeting (Appendix I), it is assumed that farmers will harvest wheat grain first and then leave residue on the ground for collection later. Farm producers neither have time nor labor to collect straw/stover themselves, necessitating the use of custom operators. The collection process begins with a custom baler that windrows the straw, if necessary, and then bales the straw/stover. A large square baler picks up the straw/stover, compacts it and then ties the residue in the form of large square bales. Each square bale is assumed to be 3’ high, 4’ wide and 8’ long, weighing 900 lbs (0.45 ton). The objective of this study is to estimate the cost of moving 1.07 million (480,000 tons) square bales from various fields within 100 mile radius to the biorefinery. It is assumed that after baling is completed, the process of moving wheat straw will be a multi-step process. First, square bales are collected from the fields and stacked on roadside. They are subsequently loaded onto trucks and driven to storage sites for unloading, stacking and tarping for rain protection. In this study, it is assumed that storage sites where the bales are temporarily stored will be located near farm fields. This scenario reduces the amount of land needed for storage at the plant and allows hauling to the plant to occur year-round. The last step will be to load bales onto trucks, throughout the year, using a loader and transport them to the final destination for further processing and energy conversion.

Several costs need to be estimated to obtain total delivery cost; these are on-farm collection cost, farm-to-storage transport cost, storage cost, and storage-to-plant transport cost. The cost estimates are developed by applying the steps described above.

On-farm Collection Cost

On-farm collection costs consist of harvesting, baling and stacking costs. The collection costs may vary depending on how much residue can be removed from the field. Due to the concerns with soil erosion, carbon and fertility loss, the amount of residues that can be removed from a field can be limited. Estimated cost data from an existing commercial firm[2] that gathers biomass on a large scale show that on-farm collection cost for wheat straw and corn stover would range from $30 per ton to $55 per ton depending on the rate of residue removal and combination of residue ratio. Low removal rate would result in high residue collection cost.

Farm-to-Storage Hauling Cost

Farm-to-storage transport cost is influenced by hauling distance shown in equation (3). By employing harvest season trucking rate data from our source and estimated farm-to-storage hauling distance data (provided in Appendix II Table 1), we computed farm-to-storage hauling costs (see Appendix II Table 2) which are reported by grid or site average within each county for wheat straw and corn stover.

Storage Cost

Storage cost comprises of land preparation and equipment costs such as costs related to facilitate handling and hauling of bales, and stacking and tarping for moisture protection. Storage cost based on our source is about $5 per ton.

Storage-to-Plant Hauling Cost

By using non-harvest trucking rate data from our source and estimated storage-to-plant hauling distance data (reported in Appendix II Table 1), storage-to-plant hauling costs are derived and shown in Appendix II Table 3 by grid average within each county. The costs are identical for both wheat straw and corn stover.

Total Hauling Cost

Using farm-to-storage hauling cost, storage-to-plant hauling cost, and loading/unloading cost from our source, total hauling costs are calculated and reported in Appendix II Table 4 for both wheat straw and corn stover. As shown in the appendix table, total hauling cost can vary from one region to another because of differences in residue densities and distances traveled among regions.

[2] We cannot reveal the source due to confidentiality agreement.

Total Delivered Cost

Total delivered cost for straw and stover can be calculated by summing total hauling, storage and on-farm collection costs. Depending on the residue removal rate, crop density and distance to the biorefinery, estimated total delivered cost for straw and stover can vary from $50 to $80 per ton. On-farm collection cost accounts for at least 54% of total delivered cost; finding a way to reduce this cost will play a critical role in making crop residues more feasible for energy production. Since increase in crop residue removal rate would reduce collection cost, one way to decrease total delivered cost is to increase the rate of residue removal. But this rate is dependent on USDA/NRCS environmental, carbon, and sustainability policy decisions.

6. Empirical Results

By incorporating the specified data and assumptions, transport models generate optimal results, which are discussed below.

100% Wheat Straw Estimation

The transport model for this case minimizes hauling costs across all possible shipment routes within the 100-mile radius of biorefinery. Estimated results are reported in Fig 6.1 (a, b and c) for a 25% removal rate and Fig 6.2 (a, b, and c) for a 50% removal rate. In the figures we imposed three assumptions for density requirement: i) no minimum density requirement, ii) minimum density requirement of 15%, and iii) minimum density requirement of 25%. All the wheat straws in green areas in each figure sum up to 480,000 tons. Fig 6.1 (a) shows that all wheat straws required by the biorefinery are harvestable within 60 to 65 mile radius zone. However, this scenario is unrealistic because it is under the assumption that even low density areas of wheat acres provide affordable wheat straws. In reality, it would be tremendously costly to harvest and collect residues in the low density areas due to diseconomies of scale of collecting as suggested in the delivered cost data. To generate more realistic outcomes, minimum density requirements are imposed in the model. Fig 6.1 (b) shows that with the density requirement of at least 15% imposed on potential harvestable sites, most potentially available wheat straws are concentrated in the area north of biorefinery, especially in counties like Wells, Foster, Griggs, Steele, Nelson, Grand Forks, Barnes and some areas in Stutsman. Fig 6.1 (c) depicts the supply locations if the minimum density requirement of 25% is imposed. Predictably, the locations of available wheat straws move farther north as a result of imposing higher density assumptions.

In a sense, there is an economic tradeoff between density and distance. North Dakota counties located farther in the north have higher wheat density than the counties located in the middle or the south. Greater density or concentration of wheat straws in the north can result in lower harvest and collection costs and more supply assurance. But the disadvantage is that more distance would have to be traveled to deliver the straw to the plant that is, an increase in hauling costs. Fig 6.2 (a, b, and c) with 50% residue removal rate assumed can be interpreted in a similar way. The main difference in Fig 6.2 (as compared to Fig 6.1) is that with 50% residue removal rate, the supply areas needed to provide 480,000 tons of wheat residues are significantly reduced which then would lower hauling costs. Table 6.1 below reports total optimal hauling costs for 480,000 tons of wheat straw by the density assumption and removal rate. It clearly shows the economic tradeoff between the density and distance. The table also indicates that if the removal rate increases to 50%, hauling cost of $690,000 can be saved annually.

Figure 6.1 (a) Estimated Potential Wheat Straw Supply Site (assumed 25% removal rate with no density assumption imposed)

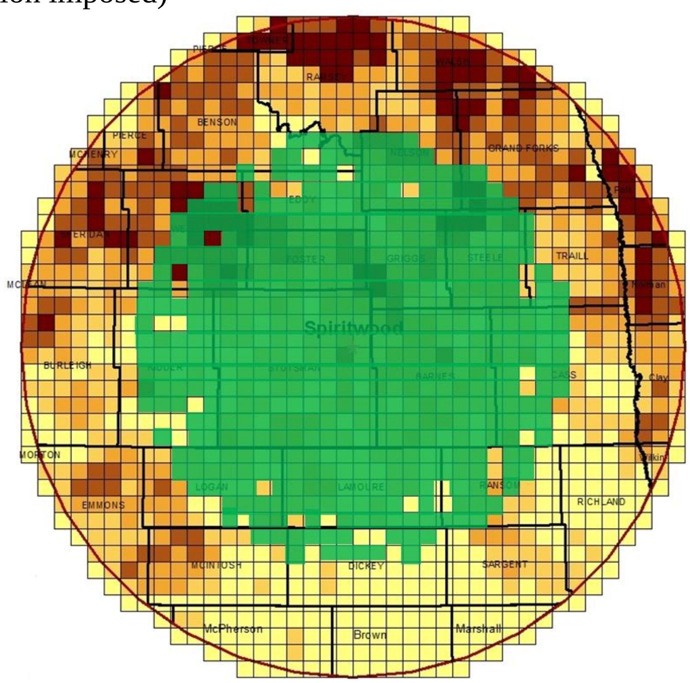


Figure 6.1 (b) Estimated Potential Wheat Straw Supply Site (assumed 25% removal rate with wheat density requirement of at least 15% in each grid)

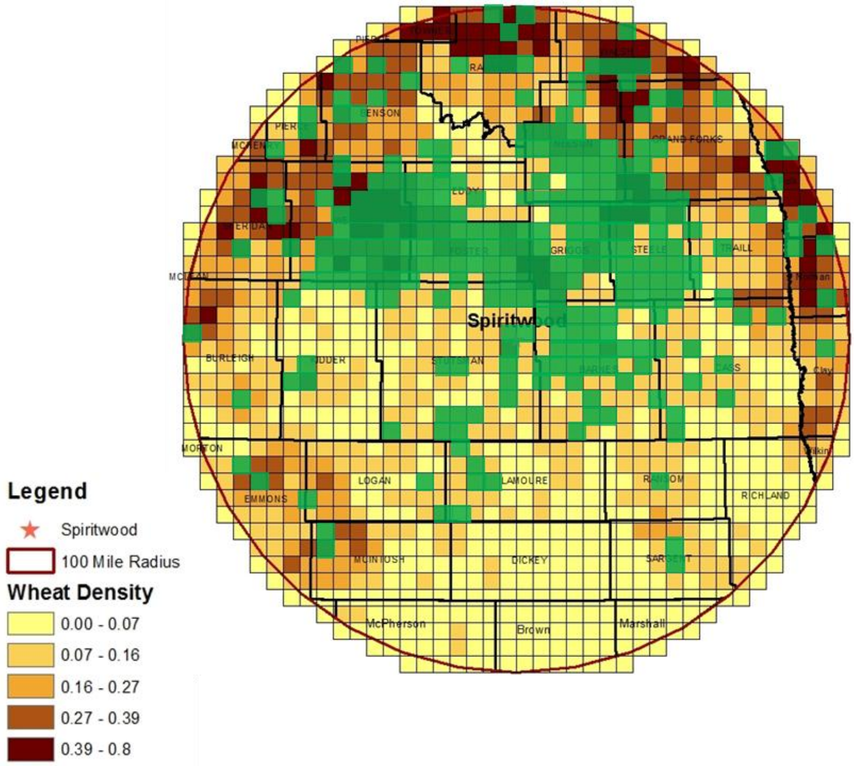


Figure 6.1 (c) (assumed 25% removal rate with wheat density requirement of at least 25% in each grid)

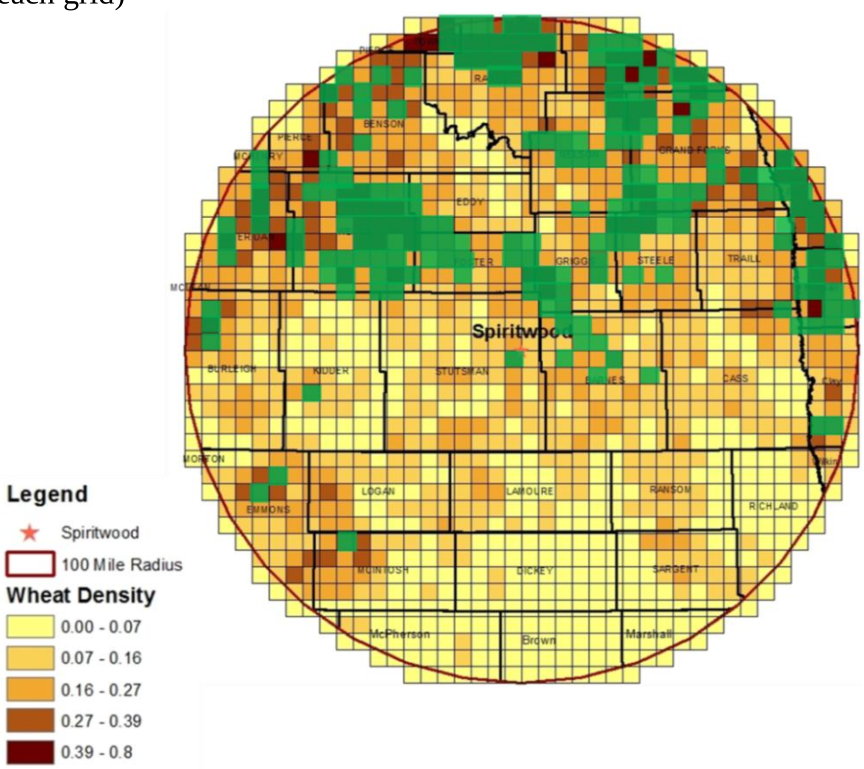


Figure 6.2 (a) Estimated Potential Wheat Straw Supply Site (assumed 50% removal rate with no density assumption imposed)

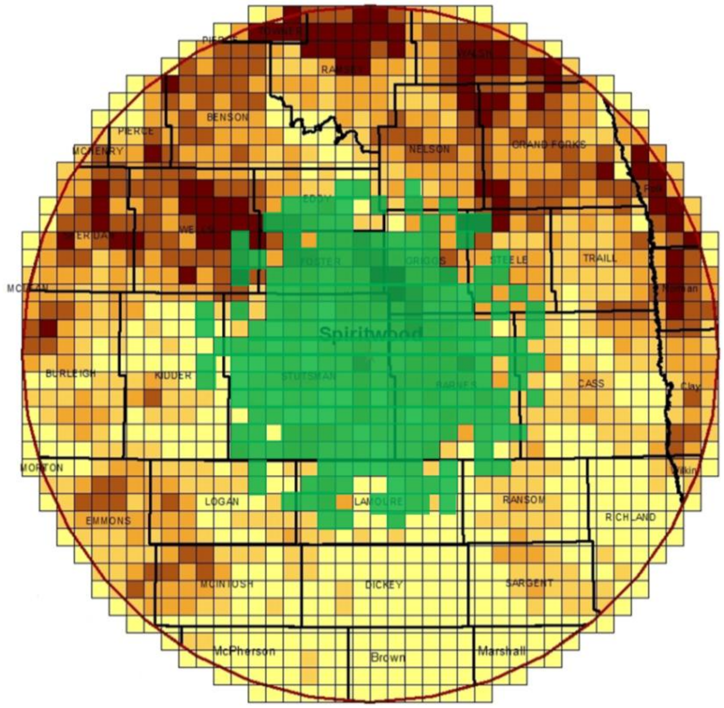


Figure 6.2 (b) (assumed 50% removal rate with wheat density requirement of at least 15% in each grid)

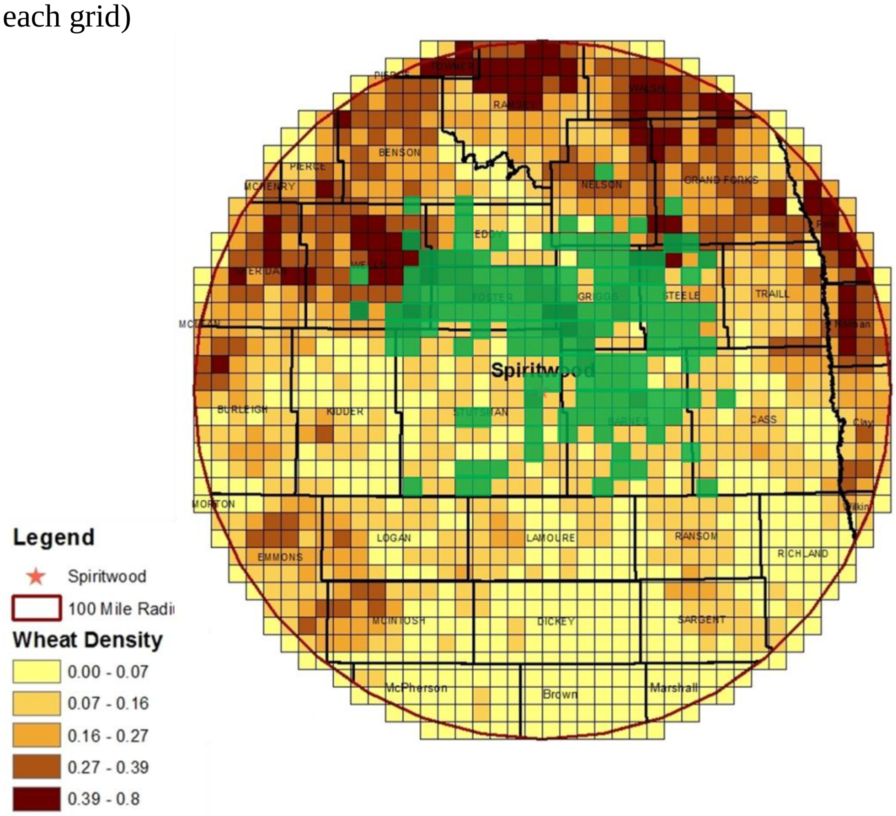


Figure 6.2 (c) Estimated Potential Wheat Straw Supply Site (assumed 50% removal rate with wheat density requirement of at least 25% in each grid)

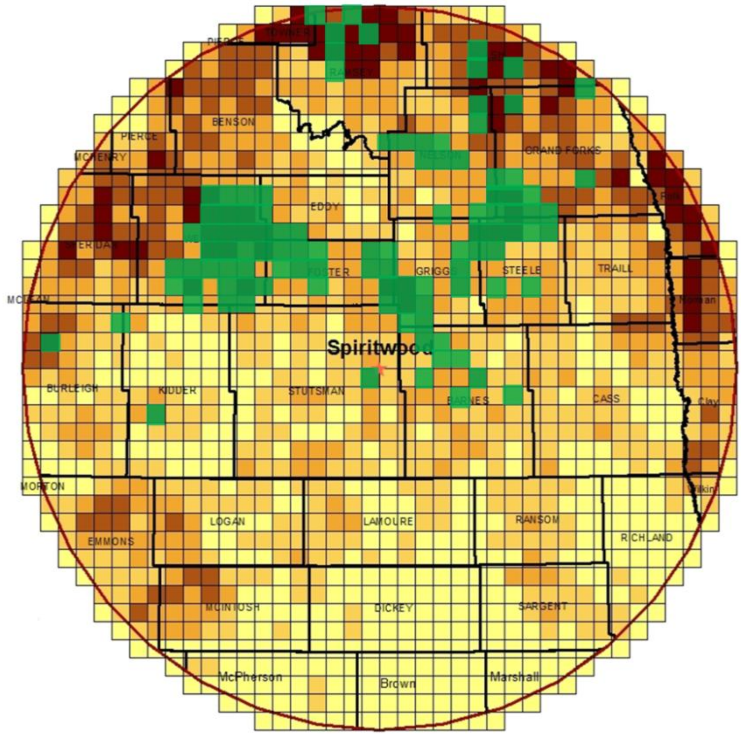


Table 6.1 Optimal Hauling Cost in Million Dollars for 100% Wheat Straw

	Removal Rate	
Density Assumption (%)	25%	50%
Zero	8.30	7.61
At least 15%	8.78	7.96
At least 25%	9.37	8.72

100% Corn Stover Estimation

Estimated results for this case are reported in Fig 6.3 (a, b and c) if the plant would operate on 100% corn stover. The results can be interpreted in a manner similar to that described in the preceding 100% wheat straw scenario. The figure shows that potential sources of corn stover would most likely come from the counties of Steele, Traill, Barnes, Cass, LaMoure, Ransom, and Dickey. Richland County has the highest concentration of stover, but the hauling distance is greater. Optimal hauling costs are reported in Table 6.2 below for 25% stover removal rate.

Table 6.2 Optimal Hauling Cost in Million Dollars for 100% Corn Stover

	Removal Rate
Density Assumption (%)	25%
Zero	8.43
At least 15%	9.06
At least 25%	9.56

Figure 6.3 (a) Estimated Potential Corn Stover Supply Site (assumed 25% removal rate with no density assumption imposed)

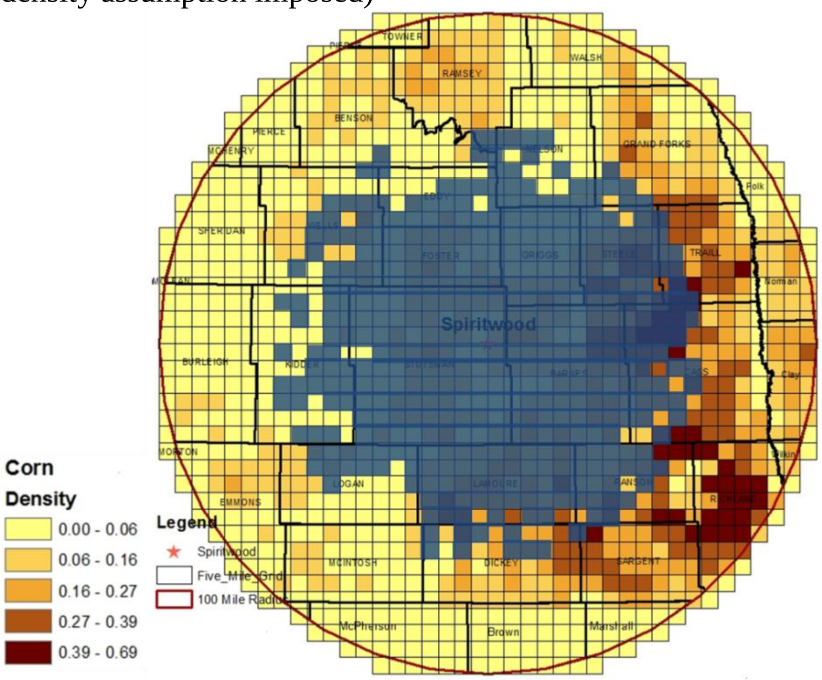


Figure 6.3 (b) Estimated Potential Corn Stover Supply Site (assumed 25% removal rate with corn density requirement of at least 15% in each grid)

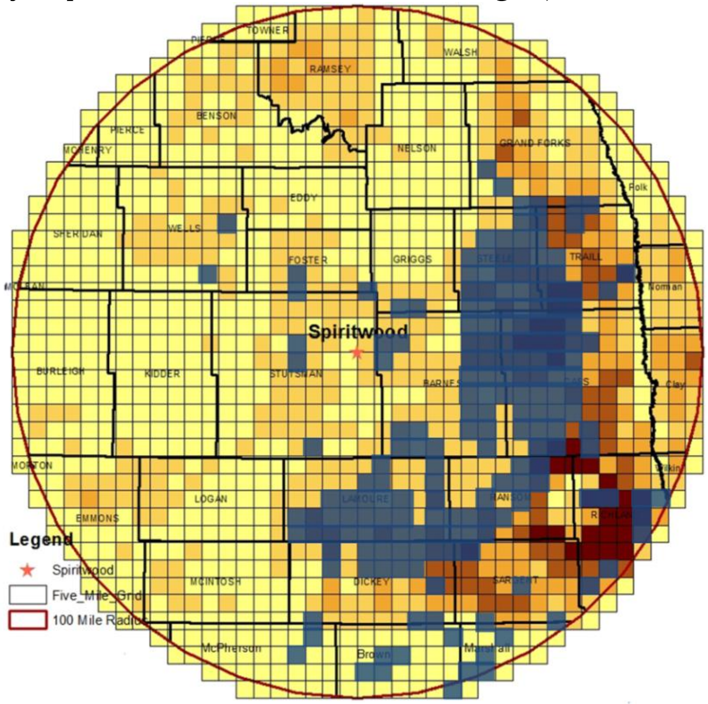
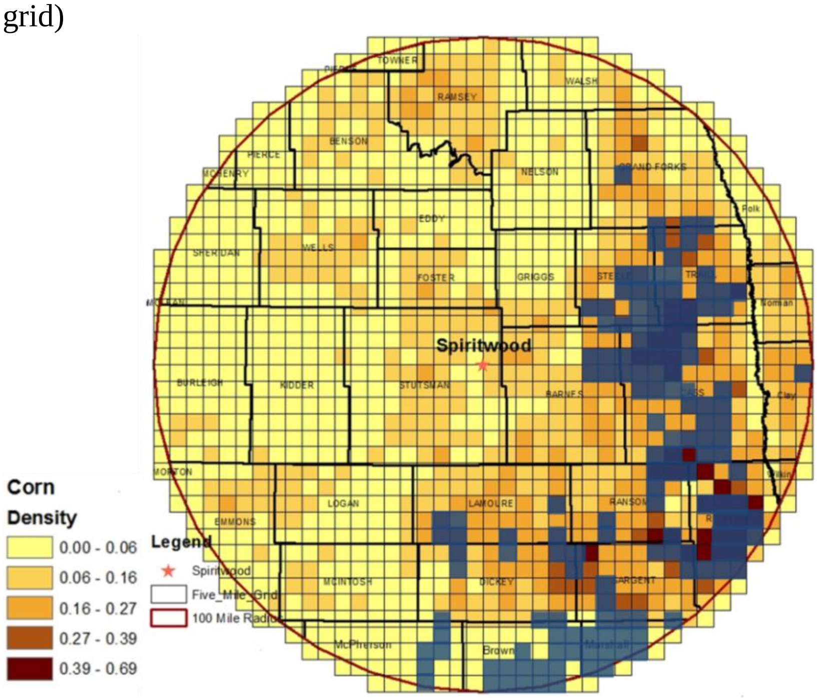


Figure 6.3 (c) (assumed 25% removal rate with corn density requirement of at least 25% in each grid)



Combination of 50% Wheat Straw and 50% Corn Stover Estimation

As discussed in the above methodology section, the transport model is modified for this scenario and estimated results are reported in Fig 6.4 (a, b and c). As can be seen in the figure, potential sources of straw and stover combination would most likely come from the following counties: Wells, Foster, Griggs, Steele, Traill, Nelson, Grand Forks, Barnes, Cass, Stutsman, LaMoure, Ransom, and Dickey. Optimal hauling costs also are reported in Table 6.3 below.

Table 6.3 Optimal Hauling Cost in Million Dollars for a Combination of 50% Straw and 50% Stover

	Removal Rate
Density Assumption (%)	25%
Zero	7.70
At least 15%	8.26
At least 25%	8.96

Figure 6.4 (a) Estimated Potential Wheat Straw (50%) and Corn Stover (50%) Supply Site (assumed 25% removal rate with no density assumption imposed)

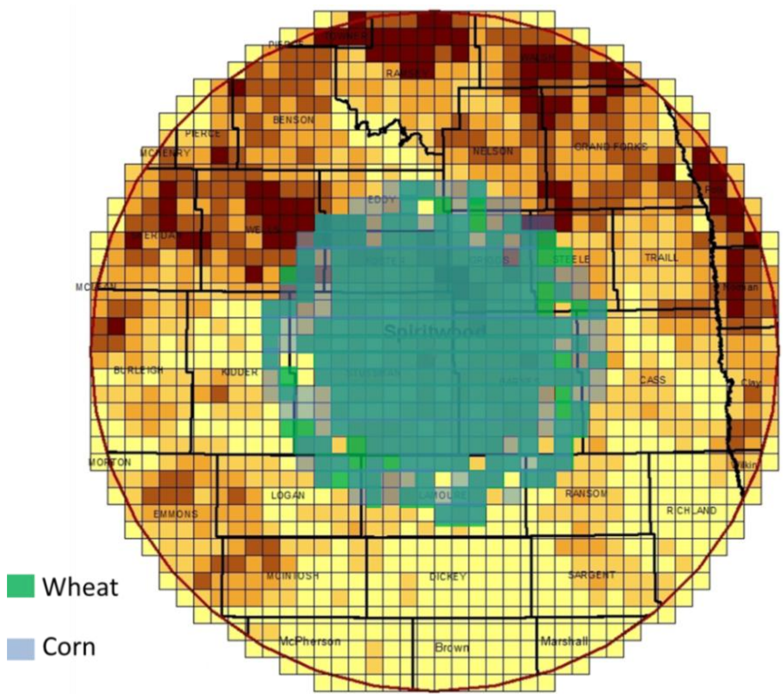


Figure 6.4 (b) Estimated Potential Wheat Straw (50%) and Corn Stover (50%) Supply Site (assumed 25% removal rate with wheat and corn density requirement of at least 15% in each grid)

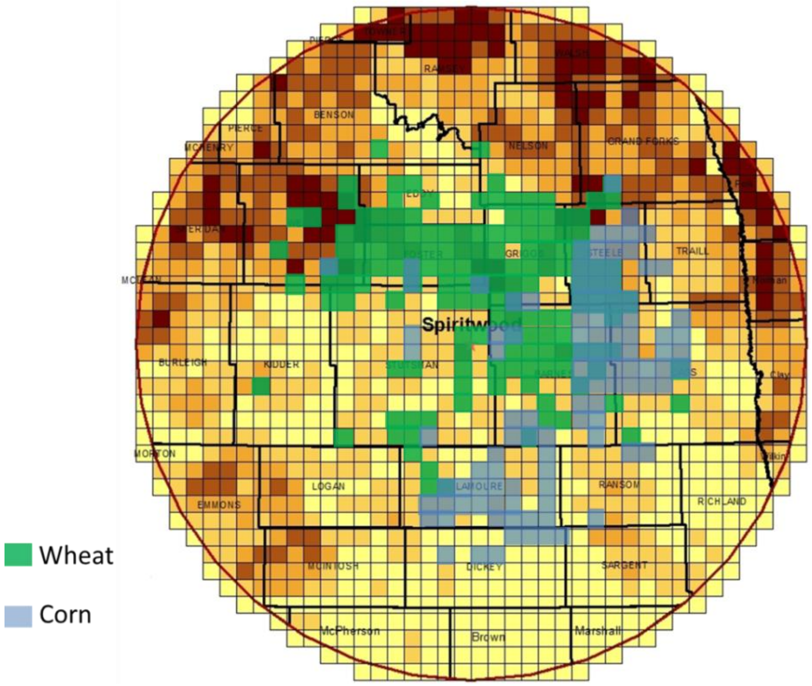
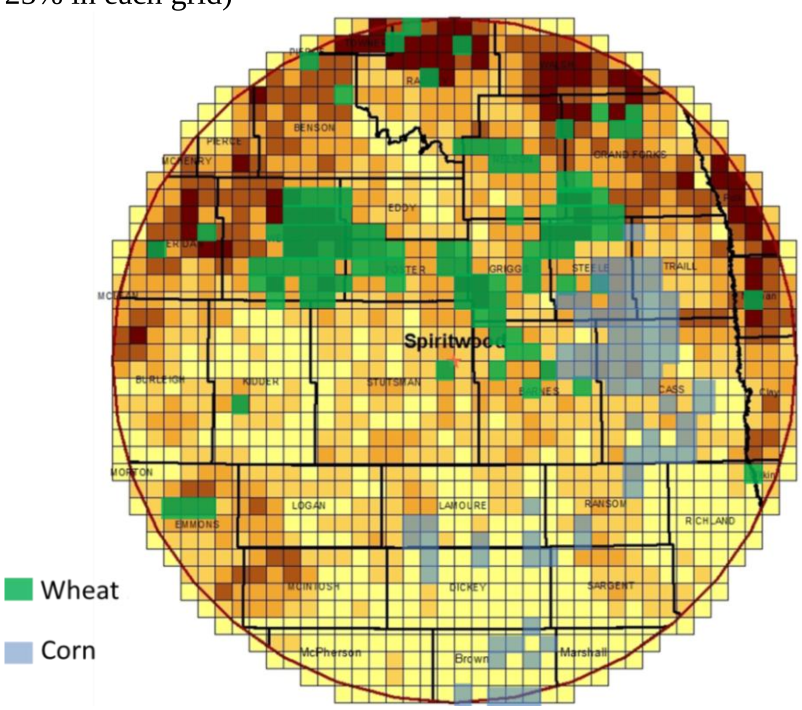


Figure 6.4 (c) (assumed 25% removal rate with wheat and corn density requirement of at least 25% in each grid)



Comparison of Optimal Hauling Cost across Different Scenarios

Optimal hauling costs are compared based on different wheat straw and corn stover individual and combination scenarios and shown in Table 6.4 below. The table reveals that optimal hauling costs for wheat (straw)-corn (stover) combined scenarios are lower than individual 100% crop residue scenarios. A combination of feedstock is likely a viable alternative. The table also shows that optimal hauling costs are not significantly different among wheat-corn combination scenarios themselves, especially between 50%Wheat-50%Corn and 60%Wheat-40%Corn scenarios.

Table 6.4 Optimal Hauling Cost in Million Dollars With 25% Removal Rate

	Density Requirement Constraint			
Scenario	Zero	At Least 15%	At Least 25%	Average
100% Wheat	8.30	8.78	9.37	8.82
100% Corn	8.43	9.06	9.56	9.02
50%Wheat-50%Corn	7.70	8.26	8.96	8.31
60%Wheat-40%Corn	7.70	8.26	8.97	8.31
70%Wheat-30%Corn	7.74	8.26	9.05	8.35
40%Wheat-60%Corn	7.71	8.29	8.97	8.32
30%Wheat-70%Corn	7.80	8.37	9.04	8.40

Potential Availability of Wheat Straw and Corn Stover

Based on above cost comparisons, the 50%Wheat-50%Corn scenario is used as a benchmark to report estimated results for straw and stover availability. The optimal amounts of straw and stover available for energy production are shown by county in Table 6.5 below. A map to illustrate this table is provided in Fig 6.4(b). The table shows that 85% of total residue needs will come from Barnes, Cass, Foster, Griggs, LaMoure, Steele, Stutsman and Wells counties.

Table 6.5 Optimal Availability of 50% Wheat Straw and 50% Corn Stover

County	Wheat Straw (ton)	Corn Stover (ton)	Total (ton)	Total (%)
Barnes	39,417	45,335	84,751	17.66
Benson	1,914	-	1,914	0.40
Cass	7,346	53,074	60,420	12.59
Dickey	-	17,705	17,705	3.69
Eddy	10,361	-	10,361	2.16
Foster	37,321	1,773	39,094	8.14
Grand Forks	7,669	1,355	9,024	1.88
Giggs	38,199	3,371	41,570	8.66
Kidder	5,614	-	5,614	1.17
LaMoure	4,785	52,385	57,170	11.91
Nelson	6,216	-	6,216	1.29
Ransom	-	11,359	11,359	2.37
Steele	21,138	36,407	57,544	11.99
Stutsman	32,756	7,184	39,940	8.32
Traill		8,955	8,955	1.87
Wells	27,264	1,096	28,360	5.91
Total	240,000	240,000	480,000	100.00

Note: 25% removal rate and density requirement of at least 15% are imposed.

7. Potential Location of Crop Residue Storage/Supply Site

To maximize hauling opportunities year around during adverse weather, potential storage or supply sites should be located near the state highways. According to North Dakota Department of Transportation (NDDOT), there are five levels of roads and highways in the state's performance classification system[3]. They are 1) interstate system, 2) interregional system, 3) state corridor, 4) district corridor and 5) district collector (Fig 7.1). Detail descriptions of highway performance classification system are explained in Appendix III. Based on analytical results presented in the prior section, and the highway classification system, potential storage sites could be located near intersections of state highways (shown with red circles in Fig 7.1) for both wheat straw and corn stover.

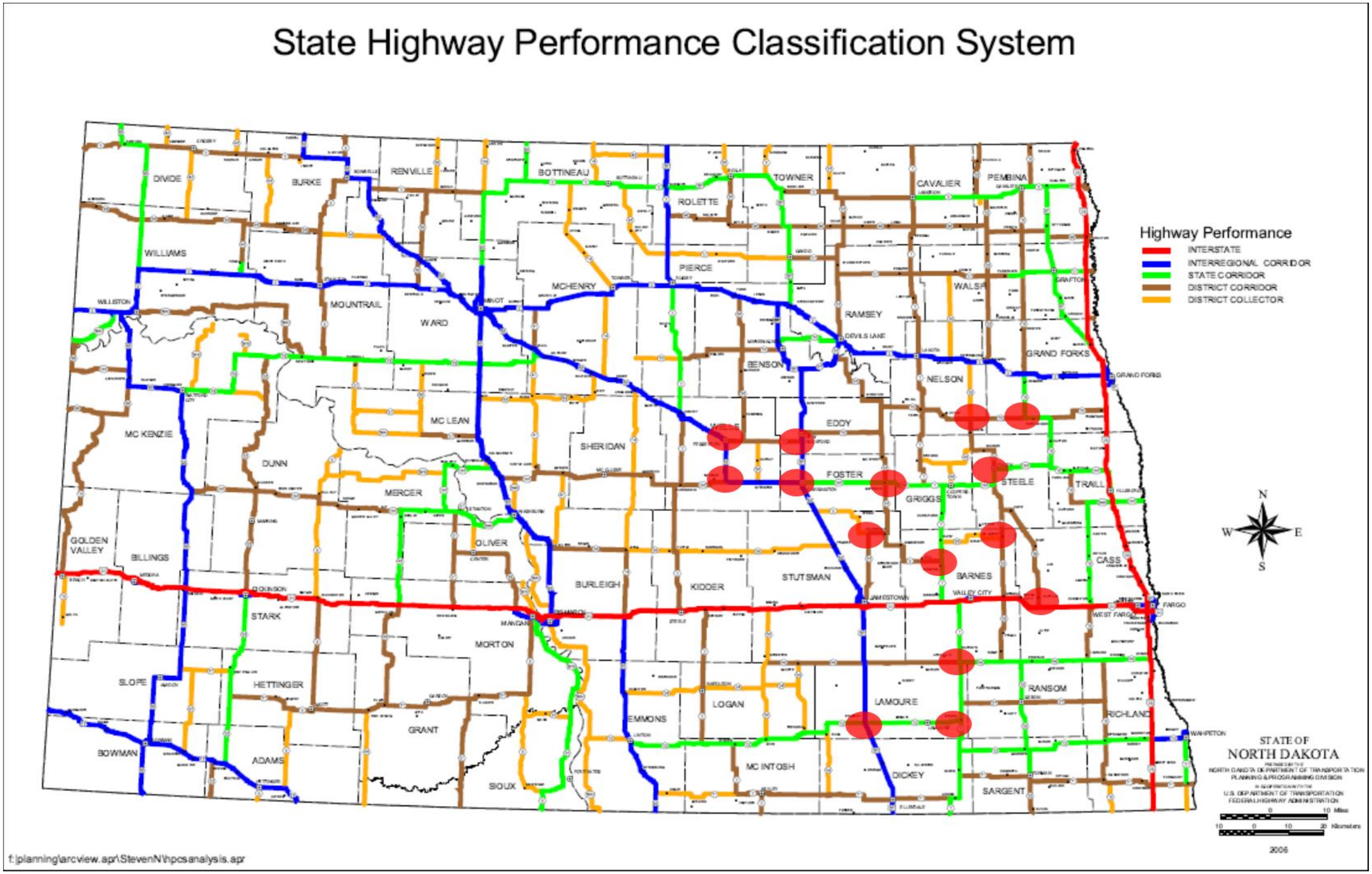
Because of better road conditions and crop residue locations, interregional highways (52 and 281 shown in blue) and state corridors (1 and 200 shown in green) would likely be the most affordable routes to transport wheat straw from the north and corn stover from the south. These

[3] All information provided for highway performance classification system is obtained from the NDDOT website: http://www.dot.nd.gov/divisions/planning/ hwyclassification.htm.

highways and corridors would be impacted due to an increase in traffic volumes as a result of crop residue transportation. Increase in traffic volumes would likely impact road pavements and result in additional costs for highway/corridor repairs.

NDDOT (2007) conducted a study which estimated the impacts to county roadways due to expansions of businesses near Jamestown, North Dakota. The study examined 2,988 total miles of county roadways. It showed that 326 of the 2,988 total miles (about 11% of total miles) of county roadways with an annual increase of greater than 200 trucks, within the 75-mile radius study area would experience significant enough impacts to quantify additional costs for roadway upkeep during the next twenty years. The study evaluated that the additional traffic loads would require an investment in excess of $8,000,000 over the next 20 years (or at least $400,000 each year) from the five affected counties: Cass, Barnes, Ransom, Stutsman, and Traill. A similar impact would be expected from the transportation of additional crop residues to the biorefinery.

Figure 7.1. Potential Wheat Straw and Corn Stover Storage/Supply Site



Source: http://www.dot.nd.gov/divisions/planning/docs/statehighwayclassificationmap.pdf

8. Summary and Conclusions

On-farm collection cost which consists of harvest, baling and stacking costs account for more than 54% of total delivered cost. Reducing this cost will increase the long term financial viability of the investment. One way to reduce the collection cost is to increase the residue removal rate. However, higher removal rates run counter to USDA/NRCS recommendations. USDA/NRCS future crop residue removal rate policies will be critically important for determining whether it is economically feasible to harvest crop residues as potential biofeedstocks for energy generation.

Our findings indicate that increase in residue removal rate would narrow the size of supply areas needed to provide total residue requirement for the biorefinery and hence result in reducing total transportation costs. There is an economic tradeoff between residue collection density and distance from the plant. Most wheat residues are highly concentrated in the north. Relying solely on wheat straw for supply needs would likely require traveling longer distances which increases total transportation costs for the plant.

Employing a combination of wheat straw and corn stover lowers total hauling costs. Costs are lowest with 50% wheat straw and 50% corn stover combination. Most straw and stover supply needs can be met from Barnes, Cass, Foster, Griggs, LaMoure, Steele, Stutsman and Wells counties. Because most crop residues are either located north or south, interregional highways and state corridors would likely be the routes used often to transport the residues, as compared to interstate highway I-94. Increased traffic volumes as a consequent of hauling crop residues would require additional investment in improving road conditions.

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Appendix I: Focus Group Meeting Summary

The summary is based on comments provided by 18 farmers who participated in a focus group session on Friday, July 16th 2010 in Jamestown North Dakota. Farmers representing each county in southeast North Dakota were invited to participate and share their interest in supplying the wheat straw and corn stover following harvest of each crop. During the focus group session, producers were asked a variety of questions regarding their current stover collection practices, existing markets, and potential interest in participating in the new market. A Turningpoint audience response system anonymously collected individual responses to several questions that participants may have been reluctant to share publicly. Other questions were posed to generate general group discussion and responses offered were noted. Attendees enthusiastically participated in a very open discussion and provided a number of thoughtful comments. The information and feedback obtained during the focus group session are summarized as follows:

- Presently few markets exist in/around the region for supplying wheat straw or corn stover.
- Both wheat straw and corn stover are available for energy generation. But, farmers may not be willing to sell all their crop residues because of concerns for harvest time limits and soil fertility losses. A few mentioned that more residues can be sold if their losses are compensated.
- There is general interest in exploring an economic opportunity to sell straw/stover. Their decisions to supply crop residues will depend on how high of a contract price the firm is willing to offer.
- Most farmers are unwilling to take any risk in supplying crop residues. To take advantage of price stability, they would prefer to sell their goods on contract than open market.
- There was little or no interest on the part of the farmer to purchase a large square baler and provide the labor. The majority prefer to have an external party bale, store and transport straw/stover. They simply do not have time for another operation and did not anticipate an adequate return to justify investing in a large square baler.
- Due to changing weather, the window for collecting straw/stover is short (a couple of days). This reinforces the need to look at both straw and stover to extend baling time. The firm requires crop residues be collected dry to prevent mold. This seems to be a challenging issue for farmers. When harvested corn stover likely contains more moisture than wheat straw. Flailing the corn stalks could enhance drying.

- More than half of the farmers indicated an interest in transferring ownership of the residue immediately after harvest. Only a few expressed interest in retaining ownership until delivery. Even in this scenario, they envision someone else baling and hauling the residue.
- Farmers would encourage the bioenergy firm to manage risk by maintaining a significant inventory of residue. Fire hazard was raised as a major concern for farmers during storage. Farmers clearly stated that they have no intent of assuming risk of supply in any form.
- Some farmers commented on cooperating to set up their own baling service but that discussion did not go too far.

Appendix II

Table 1. Estimated Farm-to-Storage and Storage-to-Plant Hauling Distances by County Average

	Farm-to-Storage Hauling Distance (Mile)		
State/County	Wheat Straw	Corn Stover	Storage-to-Plant Hauling Distance (Mile)
ND			
Barnes	1.96	1.84	31.69
Benson	1.93	4.30	98.34
Burleigh	3.07	7.36	108.60
Cass	2.55	1.31	80.78
Dickey	7.23	1.92	86.21
Eddy	2.40	4.25	59.12
Emmons	5.70	4.73	114.88
Foster	1.42	2.84	37.01
Grand Forks	1.32	2.18	99.77
Griggs	1.72	3.39	36.53
Kidder	3.41	6.12	70.36
La Moure	2.89	1.50	53.97
Logan	3.15	5.14	74.79
McHenry	2.16	12.59	123.99
McIntosh	2.81	4.53	98.51
Nelson	1.66	4.29	75.65
Pierce	2.69	12.58	118.72
Ramsey	1.80	2.70	104.49
Ransom	5.50	1.46	74.40
Richland	6.67	1.29	112.33
Sargent	4.21	1.14	103.46
Sheridan	2.39	10.50	113.90
Steele	1.58	1.45	58.49
Stutsman	2.46	3.17	27.45
Towner	1.37	4.61	124.01
Traill	1.96	1.16	88.60
Walsh	1.96	5.97	119.69
Wells	1.31	3.29	78.35

Table 2 Wheat Straw and Corn Stover Hauling Costs by County Average (assumed 25% residue removal rate)

	Farm-to-Storage Hauling Cost ($/ton)	
State/County	Wheat	Corn Stover
ND		
Barnes	4.44	4.44
Benson	4.44	4.55
Burleigh	4.48	4.85
Cass	4.44	4.44
Dickey	4.90	4.49
Eddy	4.44	4.52
Emmons	4.83	4.65
Foster	4.44	4.44
Grand Forks	4.44	4.44
Griggs	4.44	4.44
Kidder	4.44	4.74
La Moure	4.44	4.44
Logan	4.44	4.69
McHenry	4.44	5.93
McIntosh	4.44	4.56
Nelson	4.44	4.44
Pierce	4.44	5.37
Ramsey	4.44	4.44
Ransom	4.89	4.44
Richland	4.91	4.44
Sargent	4.70	4.44
Sheridan	4.51	5.43
Steele	4.44	4.44
Stutsman	4.44	4.47
Towner	4.44	4.44
Traill	4.44	4.44
Walsh	4.44	4.60
Wells	4.44	4.44

Table 3 Storage-to-Plant Hauling Cost by County Average for Both Wheat Straw and Corn Stover

State/County	Storage-to-Plant Hauling Cost ($/ton)
ND	
Barnes	7.67
Benson	12.58
Burleigh	12.84
Cass	11.80
Dickey	12.26
Eddy	10.32
Emmons	12.84
Foster	8.56
Grand Forks	12.68
Griggs	8.29
Kidder	11.15
La Moure	9.91
Logan	11.51
McHenry	12.84
McIntosh	12.76
Nelson	11.51
Pierce	12.84
Ramsey	12.78
Ransom	11.50
Richland	12.84
Sargent	12.84
Sheridan	12.84
Steele	10.30
Stutsman	7.16
Towner	12.84
Traill	12.34
Walsh	12.84
Wells	11.75

Table 4 Total Hauling Cost for Wheat Straw and Corn Stover

	Total Hauling Cost ($/ton)	
State/County	Wheat Straw	Corn Stover
ND		
Barnes	15.61	15.61
Benson	20.52	20.63
Burleigh	20.83	21.20
Cass	19.74	19.74
Dickey	20.66	20.25
Eddy	18.26	18.33
Emmons	21.18	20.99
Foster	16.50	16.50
Grand Forks	20.63	20.63
Griggs	16.23	16.23
Kidder	19.09	19.39
La Moure	17.85	17.85
Logan	19.46	19.71
McHenry	20.79	22.27
McIntosh	20.71	20.82
Nelson	19.45	19.45
Pierce	20.79	21.71
Ramsey	20.73	20.73
Ransom	19.89	19.45
Richland	21.25	20.79
Sargent	21.04	20.79
Sheridan	20.85	21.77
Steele	18.24	18.24
Stutsman	15.10	15.13
Towner	20.79	20.79
Traill	20.28	20.28
Walsh	20.79	20.95
Wells	19.69	19.69
Average	**19.53**	**19.64**

Appendix III: Highway Performance Classification System (Source: NDDOT)

There are five levels of highway performance classification system (Figure 7.1) and they are: 1) interstate system, 2) interregional system, 3) state corridor, 4) district corridor and 5) district collector.

1) Interstates like I-29 and I-94 have the highest volumes of annual automobile and truck traffic in the state. Average travel speeds could range from 65 to 75 miles per hour. These interstate highways have multiple-lanes, full-access control, paved shoulders, load limits are restricted by legal weights, and are considered very safe. The goal of NDDOT is to make the interstates free of height restrictions and to provide a good to excellent ride quality.

2) Interregional highways have moderate to high volumes of automobile and truck traffic. Average travel speeds could range from 60 to 75 miles per hour. The highways are either two-lane or multiple lane facilities, may have partially controlled accesses, and generally have paved shoulders. The interregional highways are free of height restrictions, have load limits restricted by legal weights, and are considered very safe. There are limited passing restrictions.

3) State Corridors have moderately high volumes of automobile and truck traffic. They support the movement of agricultural commodities, freight, and manufactured products within the state. They also provide connections between lower and higher level roadways. Average travel speeds could range from 60 to 65 miles per hour. The Corridors are typically two-lane facilities that have segments or locations with partially controlled access, either paved or aggregate shoulders. They have limited passing zone restrictions and load limits are restricted by legal weights. Bridges and overhead structures provide for the unrestricted movement of legal loads.

4) District corridors have moderate volumes of automobile and truck traffic, with occasional increases in seasonal traffic volumes and truck movements. Average travel speeds could range from 55 to 65 miles per hour. The Corridors are two-lane highways and access control is not usually purchased. These roads have narrow paved or gravel shoulders, segments with restricted passing zones, 8-ton or 7-ton seasonal load limits. Bridge structures provide for the unrestricted movement of legal loads.

5) District Collectors have low volumes of automobile and truck traffic. But, truck movements may increase during spring planting and fall harvest periods. Since these roads are generally shorter routes providing connections to the higher road level systems, traffic is

primarily short distance, local, or farm to market and maintaining reliability and mobility on these highways is a lower priority. Average travel speeds could range from 50 to 55 miles per hour. District Collectors are two-lane roads and access control is usually not purchased. These roads generally have no shoulders and have restricted passing zones. Seasonal load limits 7-ton or 6-ton are normal on these roads, although some segments may have year round restrictions. Bridge structures provide for the movement of typical legal loads, but some structures have load, height, and width restrictions.