USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No 016PY01

Transportation Infrastructure Implications of Development of a Cellulose Ethanol Industry for Indiana

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TECHNICAL SUMMARY

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Introduction

The 2007 Energy Independence and Security Act calls for the US to produce 36 billion gallons of biofuels by 2022 of which no more than 15 billion would come from corn and 1 billion of biodiesel. Thus, the legislation envisions moving from no cellulose ethanol production today to as much as 20 billion gallons by 2022.

In this research project, we estimate the transport system impacts of different levels of cellulose production in Indiana. A scenario approach is used for the transport of cellulosic materials to central plants. Transporting cellulose materials to a central processing plant requires more bulk material than for a corn ethanol plant. We use an integer programming model to locate and size cellulosic plants in Indiana. This model optimizes plant location given the potential cellulosic production from corn stover and other cellulosic inputs in each part of the state. Cellulose supply curves are developed for each sub-region in the state. We introduce different scenarios of cellulose development to compare with the base case of no cellulosic ethanol production.

The growth of the ethanol industry could be a major mechanism for rural economic development, especially in Region V. Cellulosic ethanol will provide the opportunity for farmers to sell agricultural waste such as corn stover, in addition to growing dedicated energy crops on less desirable land. The emergence of this cellulose-based ethanol industry will create a number of new transportation needs in Region V, along with new business opportunities for transportation firms.

Findings

The development of a commercial cellulosic biofuels industry in biomass rich states such as Indiana would likely cause substantial impacts on road infrastructure. We assume that 100 percent of the biomass needed for the future cellulosic plants will be sourced locally, thus requiring the use of semi trucks to transport the biomass from the fields to centralized cellulosic biofuel facilities. This research took a case study approach to estimating the infrastructure impacts of cellulosic biofuel production by projecting the impacts of three selected Indiana cellulosic facility sites. The study produced the following key results:

- Average loaded vehicle trip miles (VTM) are projected to be 201 to 683 percent higher per gallon of cellulosic biofuel capacity compared to the VTM per gallon of capacity for grain based ethanol.

- Average ton-miles per gallon of capacity for cellulosic biofuel production is projected to be 98 to 432 percent higher compared to the average ton-mile for grain based ethanol

- The average length of haul (LOH) required to source an adequate supply of biomass will increase as more plants are built in a given region. Thus, the first commercial plant built should have the smallest infrastructure impact.

The study analyzed two scenarios that varied the effective supply of biomass to a given plant by changing the farmer participation and sustainable removal rates. In addition, a third scenario projected the infrastructure impacts that would result from a higher biomass to biofuel conversion rate. A higher biofuel yield rate would decrease the tons of biomass required for a given plant and subsequently

We calculated the total VTMs for each of the scenarios in addition to the total direct VTM impact of the grain based ethanol industry in Indiana. The total VTMs were divided by the total gallons of biofuel produced, thus allowing comparison between the smaller cellulosic facilities and the larger grain based ethanol facilities. The VTM per gallon of biofuel produced is 318 percent higher in scenario 1 and 683 percent higher in scenario 2 when compared to the Indiana grain based ethanol industry (Quear, 2008). The NREL biofuel conversion estimate is projected to have a 201 percent greater VTM impact per gallon of capacity when compared to the grain based ethanol industry. It should be noted that scenario 1 is considered the 'best case' scenario for first generation cellulosic plants in this case study. Thus this study suggests that the infrastructure impact on a per gallon basis of cellulosic biofuel produced is sustainably higher than a gallon of grain based ethanol produced. In addition, the VTM's reported for the grain based industry as established by Quear, only include the VTM's impacted from direct incoming corn and outgoing DDGS. Quear suggested that the actual VTM impact for the grain based ethanol industry in Indiana is much less than reported as shifts in livestock consumption, crushing and exporting will change, thus lowering the total VTM caused by an increase in ethanol production (Quear, 2008).

This study focused solely on the infrastructure impacts of a cellulosic industry in Indiana, although the impacts likely would be similar for neighboring or similar states.

Recommendations

As the cellulose industry begins to develop, it is important that local and regional transportation officials take into consideration the large increase in road traffic that will be engendered by cellulosic biofuels. Since no plants exist today, infrastructure planning can take place along with the development of the industry. It is important that this coordinated development occur.

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ABSTRACT

The development of a commercial cellulosic biofuels industry in biomass rich states such as Indiana would likely cause substantial impacts on road infrastructure. We assume that 100 percent of the biomass needed for the future cellulosic plants will be sourced locally, thus requiring the use of semi trucks to transport the biomass from the fields to centralized cellulosic biofuel facilities. This research took a case study approach to estimating the infrastructure impacts of cellulosic biofuel production by projecting the impacts of three selected Indiana cellulosic facility sites. The study produced the following key results:

- Average loaded vehicle trip miles (VTM) are projected to be 201 to 683 percent higher per gallon of cellulosic biofuel capacity compared to the VTM per gallon of capacity for grain based ethanol.
- Average ton-miles per gallon of capacity for cellulosic biofuel production is projected to be 98 to 432 percent higher compared to the average ton-mile for grain based ethanol
- The average length of haul (LOH) required to source an adequate supply of biomass will increase as more plants are built in a given region. Thus, the first commercial plant built should have the smallest infrastructure impact.

The study analyzed two scenarios that varied the effective supply of biomass to a given plant by changing the farmer participation and sustainable removal rates. In addition, a third scenario projected the infrastructure impacts that would result from a higher biomass to biofuel conversion rate. A higher biofuel yield rate would decrease the tons of biomass required for a given plant and subsequently reduce the infrastructure impacts.

This study focused solely on the infrastructure impacts of a cellulosic industry in Indiana, although the impacts likely would be similar for neighboring or similar states.

1. INTRODUCTION

1.1 Overview

Since 2004, ethanol production capacity in the United States (U.S.) has increased drastically; from 3.1 billion gallons per year (BGY) in 2004 to a January 2009 capacity of 10.6 BGY (Renewable Fuels Association, 2009). Currently, almost all of the ethanol produced in the U.S. stems from ethanol fermented from corn.

The rapid increase of grain based ethanol production in the U.S. likely resulted from high oil prices, federal mandates and a continued fixed subsidy program (Tyner, 2008). Though these initiatives were successful in increasing ethanol production, many believe they led to higher commodity prices; affecting both livestock producers who rely on corn as a feedstuff and world consumers who purchase grain and meat products. In fact, the previous blending subsidy of 51 cents per denatured gallon was said to increase the price of corn by $1.07 per bushel (Abbott et al, 2008). Because of the negative externalities associated with producing grain based ethanol, there has been political pressure to start producing advanced cellulosic biofuels.

Cellulosic biofuels are gaining attention as a possible solution to decrease our dependency on foreign oil and produce a cleaner burning fuel while not significantly affecting the price of agricultural commodities. The key distinction between grain based ethanol and cellulosic biofuel production is that the cellulosic production can utilize any organic material to produce biofuels; namely wood wastes, corn stover or switchgrass. Two processes, biochemical and thermochemical production, are both advanced cellulosic production methods that likely will be utilized in the United States. Though both of the advanced biofuel production pathways hold promise; there are currently no commercial scale cellulosic plants in the production or construction phases in the U.S.

Cellulosic plants have been regarded as uneconomical in the U.S., especially compared to grain based ethanol. A 2007 study concluded it cost 44% more to produce cellulosic biofuels than grain based ethanol; largely due to the high capital costs associated with building the plants (Wright and Brown, 2007). However, assuming technology continues to progress, it is possible that cost will decrease for cellulosic plants; making cellulosic biofuels economically feasible.

To jumpstart the advanced biofuel industry, the United States Congress passed the "Energy Independence and Security Act of 2007" which mandates the use of advanced biofuels. The Energy Independence and Security Act of 2007 amends the "Renewable Fuels Standard (RFS)" that was signed into law in 2005. An important aspect of this legislation is that 21 billion gallons of the mandated biofuels must derive from advanced biofuels; such as cellulosic ethanol, and 16 of the 21 billion must come from cellulosic feedstocks (U.S. Congress, 2007). In addition to this mandate, the 2008 Farm Bill created subsidy differentiation based on how the biofuel is produced. The 51 cents blending subsidy for all ethanol was reduced to 45 cents per denatured gallon for the grain based platform in January 2009, and the effective subsidy for cellulosic methods was increased to $1.01 per gallon (U.S. Congress, 2008). These increased subsidies and mandates could spur investment in advanced biofuels especially in biomass rich areas such as Indiana, if investors believe they will be upheld throughout the investment life[1].

If cellulosic plants are presumed to be profitable by investors, the cellulosic industry will face unique logistical issues compared to the established grain based ethanol industry. Contrary to the rapid plant growth witnessed in the grain based ethanol industry, the cellulosic industry will likely develop at a slower pace as technology emerges. Increased planning will allow investors to select plant sites that minimize transportation costs of both feedstuffs and the finished biofuel product. The cellulosic biofuels industry will likely develop in Midwestern states like Indiana, where high levels of corn production produce a supply of unused corn stover. Unlike the grain based industry, the cellulosic facilities will likely rely solely on local materials for its feedstuff, thus increasing local truck traffic and the burden on local road infrastructure. Rail will only be used to move the finished biofuel product as cellulosic plants will not likely produce a saleable byproduct that requires transportation.

This report is the first to fully examine the impacts that the cellulosic biofuel industry will have on Indiana roadways. Cellulosic biofuel plants will significantly increase demand for local trucks that will deliver locally produced biomass. This study

[1] Currently the cellulosic subsidy is set to expire in 2012.

will follow a framework similar to the 2008 publication, *The Impacts of Biofuel Expansion on Transportation and Logistics in Indiana* (Quear, 2008), that estimated the impact of the grain based ethanol industry on Indiana's infrastructure but will be modified to reflect the unique impacts that the cellulosic industry will impose.

1.2 Objective and Approach

The key objective of this study is to determine the impacts that inbound biomass transportation will have on the road infrastructure in terms of truckloads of biomass, average length of haul (LOH), and total vehicle trip miles (VTM). Specifically this study will predict the concentration and location of inbound trucks that will be used to carry the biomass needed for future large scale cellulosic plants in Indiana. Because there are currently no commercial cellulosic plants in operation, this study will look at a base scenario and alternative scenario which reflect differences in farmer participation in terms of producing biomass and the amount of biomass that can effectively be removed from the land.

The first step in determining how the cellulosic biofuel industry will affect the road infrastructure is to determine where the cellulosic plants will be physically located. The absence of cellulosic plants allows investors and planners to choose the 'ideal' cellulosic plant locations in the state based on minimizing costs. It is assumed that each plant will have an a identical capital and operating cost structure with the exception of biomass cost, which will vary depending on transportation distance to the plant. Using work from a previous M.S. Purdue student (Brechbill, 2008), a doctorial candidate at Purdue University has predicted the ideal plant locations in Indiana using a linear programming model that minimizes the distance required to supply the biomass needed for 50 million gallon per year plants (Perkis, 2008). This research resulted in the least cost cellulosic plant locations in Indiana, ranked from 1 to 9 with 1 being the best plant location.

Step two uses the plant location output from step one to calculate the actual available biomass within each 5 mile buffer ring around the top three ideal cellulosic plant locations. The biomass buffer rings will be developed using the Arc GIS mapping software. Data from the "billion ton study" will be used to identify available biomass within each of the buffer rings on a county level basis (Perlack et al. 2005). Once available biomass is calculated, a spreadsheet will determine the number of trucks required to transport biomass at various distances surrounding a particular cellulosic plant.

Step three will be to determine which road types will likely be used to transport the incoming biomass to the cellulosic plants. Data from the Federal Highway Administration (FHWA) along with an Arc GIS road overlay will be used predict the proportion of incoming biomass truck traffic that will occur on each of the FHWA functional road classes (U.S. Department of Transportation, 2009). Steps two and three will both occur for the base case and the alternative scenario.

Step four will be to determine the impacts on Indiana road infrastructure for both the base and alternative scenario. The outputs of this analysis will include truckloads of biomass required, one-way loaded vehicle trip miles (VTM), average length of haul (LOH), and VTM by functional road class (FC). The first three outputs will mirror Quear's 2008 study that focused on infrastructure impacts of the grain based industry but will be altered slightly to account for overlapping fuelsheds. The outputs for both the base and alternative scenarios will give planners and investors the approximate best and worst case scenarios in terms of biomass collection and road infrastructure impacts. Perhaps most important, the methods used in this research can be adapted for any future plant locations that might be chosen.

1.3 Organization

This study was designed to estimate the infrastructure impacts of the cellulosic biofuel industry in Indiana. In section two, an extensive review of the literature will be conducted providing previous results and methodologies for estimating road impacts. Section three will consist of the data, assumptions and study methodology. Section four will outline the empirical infrastructure impact results on Indiana roadways. Finally, the last section will include conclusions, study limitations, and future research suggestions.

2. LITERATURE REVIEW

2.1 Overview

This section will examine the literature related to transportation issues within the corn based ethanol and cellulosic biofuel industries. It should be noted that very little literature exists about the specific issues studied in this thesis; thus, much of the literature reviewed is indirectly related to the subject.

2.1.1 Infrastructure Literature Review

In order for the cellulosic biofuel industry to develop in Indiana or any other state, the cellulosic facilities will need to have access to adequate supplies of biomass. A study completed in 2008 by Brechbill & Tyner addressed issues such as biomass production and transportation costs, biomass availability in Indiana, and developed biomass supply curves for three potential Indiana biomass power plants (Brechbill & Tyner, 2008).

The study reported that biomass transportation costs represent a significant portion of the total cost per ton that the cellulosic plant will incur for biomass. Brechbill & Tyner state that each ton of biomass transported incurs a marginal transportation cost of approximately 28 cents per mile if using custom equipment (Brechbill & Tyner, 2008). In addition to the marginal transportation cost, Brechbill & Tyner included a fixed cost of $1.15 per ton; which represents the labor expenses incurred for the loading and unloading of the biomass. Table 2.1 shows the estimated total transportation costs for transportation of biomass at varying distances. The Brechbill & Tyner study assumes that the transportation costs are linear, that is, there are no economies of distance for the transport component alone (Brechbill & Tyner, 2008). It should be noted that the $2.53 cost estimation for transporting biomass 5 miles includes the total $1.15 expense that is incurred for loading and unloading the biomass.

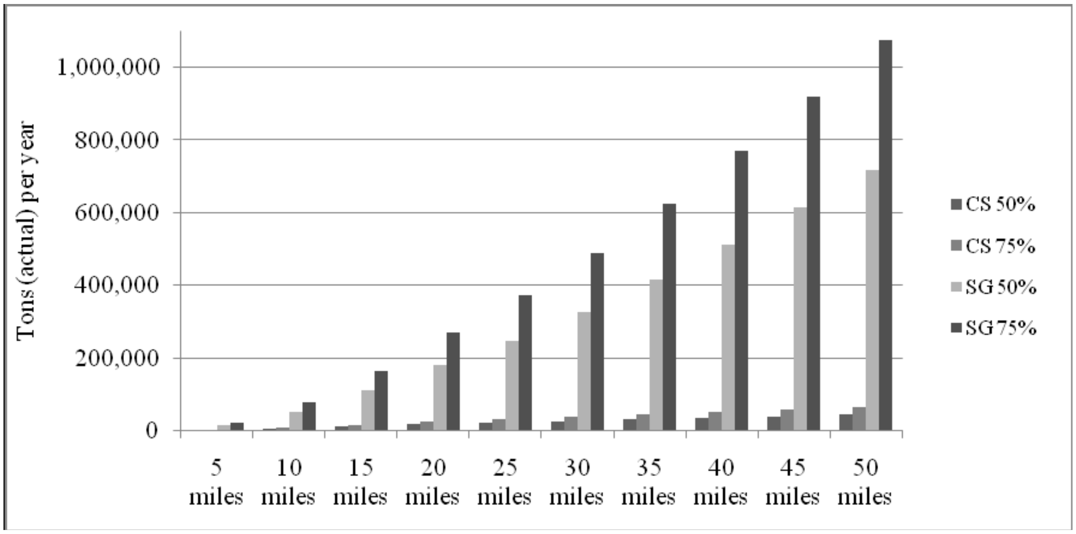
Table 2.1: Transportation per Ton Cost with Custom Equipment

Distance from Cellulosic Plant	$ per ton
5 Miles	$2.53
10 Miles	$3.92
15 Miles	$5.30
20 Miles	$6.69
25 Miles	$8.07
30 Miles	$9.46
35 Miles	$10.84
40 Miles	$12.23
45 Miles	$13.61
50 Miles	$15.00

Source: Brechbill & Tyner (2008)

The study also established estimates for the removal rates of corn stover based on sustainable levels. That is, the level at which corn stover can feasibly and sustainably be collected from the land. They established removal rates of 38, 52.5 or 70 percent depending upon harvest and sustainability assumptions. Thus, the average sustainable removal rate is 53.5 percent with the worse case removal rate being 38 percent (Brechbill & Tyner, 2008). These removals rates were used in conjunction with data from the Million Ton Study and a farmer participation rate to establish the actual available biomass within each Indiana County.

Biomass supply curves were constructed for three potential Indiana biomass power plants using the Arc GIS mapping software. In addition to the estimated 53.5 percent sustainable removal rate, available biomass was calculated with two farmer participation levels; 50 and 75 percent (Brechbill & Tyner, 2008). The study calculated the available biomass within each buffer distance by using the above removal and participation levels and data from the Oak Ridge Laboratory that provided the total biomass available within each county. Figure 2.1 shows the supply of biomass at varying distances for one of the Indiana power plants.



Source: Brechbill & Tyner (2008)

Figure 2.1: Area Biomass Supply, Knox County Plant

A 2008 study by Quear focused on the impacts of grain based biofuel expansion on the transportation infrastructure network in Indiana. The study included infrastructure impacts of both inbound and outbound transportation of corn, soybeans, DDGS and ethanol within Indiana (Quear, 2008). Three time frames were used for this study, a baseline of 2006, a short term time frame of 2008 and a long term scenario based in 2010.

The 2008 Quear study focused primarily on the current and future grain based ethanol industry in Indiana. The study used a linear programming method to minimize the transportation distances required to satisfy the corn demand by the livestock, food and ethanol industries. In addition, a linear programming model was established to minimize the transportation distance for outbound products such as DDGS and ethanol. The study assumed that inbound and outbound products could travel via truck, rail, or barge (Quear, 2008).

Quear calculated the Indiana roadway infrastructure impacts for each time frame by calculating the one way vehicle trip miles (VTM) as well as establishing the average length of haul (LOH). Quear used the following formula to calculate the VTM.

$$VTM = \left(\sqrt{\frac{Truck\ \#\ X\ Truck\ Capacity}{\left(\frac{\pi\ X\ Crop\ Density}{Days\ in\ Operation}\right)}}\right) * Circuity\ Factor$$

Source: Quear (2008).

In addition to the VTM calculation, Quear also estimated the average length of haul (LOH) for trucks travelling on Indiana roadways. This metric was determined based on the following equation.

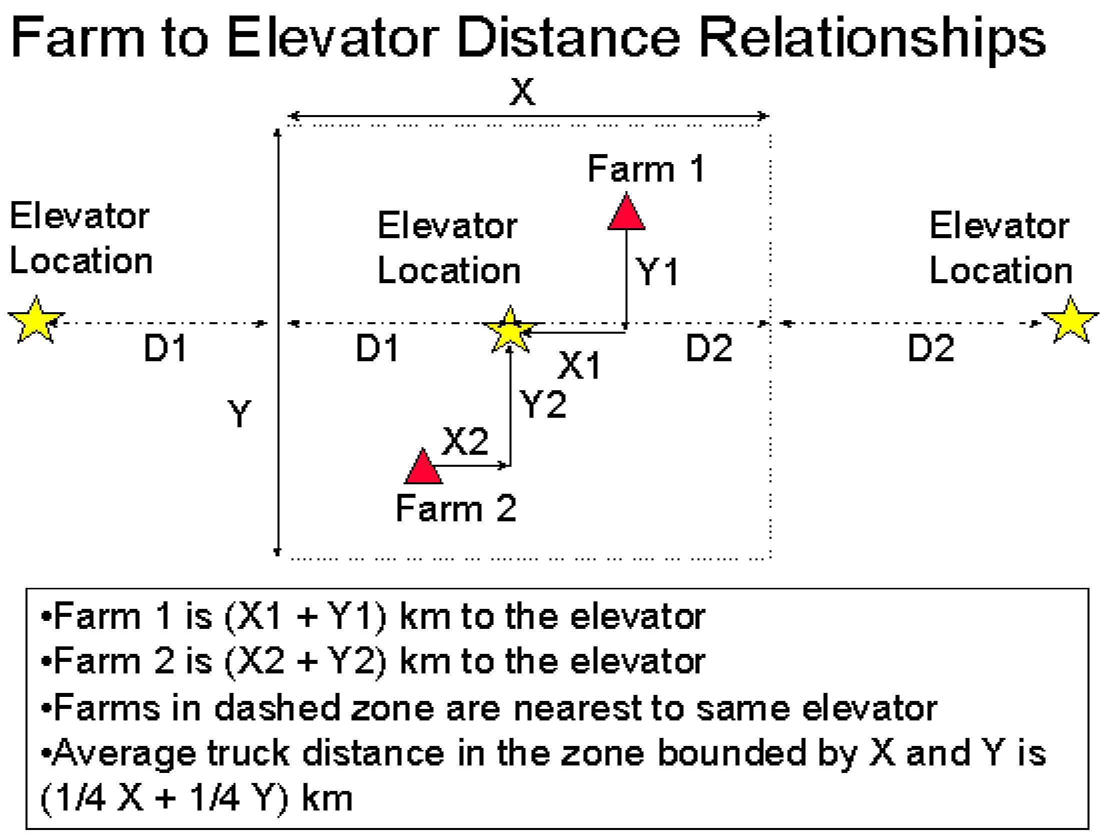
$$LOH = \left(\frac{VTM}{\#\ of\ Trucks}\right)$$

Source: Quear (2008).

The study concluded that the total VTM for all of the commodities being affected by the grain based ethanol industry would increase for each of the time frames studied for both inbound and outbound VTM's. Quear estimated that the grain based ethanol industry would increase the total VTM on Indiana roadways from 31,015,500 miles in 2006 to 45,060,400 VTM's in 2010 with the largest gain coming from corn transportation to ethanol facilities (Quear, 2008).

A 1999 study conducted by Trimac Consulting Services LTD for the Transport Canadian Surface Policy and Programs explored the road infrastructure impacts of grain truck traffic. The study explored how the consolidation of the grain elevator industry affected the average length of haul for trucks and the total truck miles traveled in Canada (Trimac, 1999).

The study estimated the average truck haul distance to the nearest elevator by assuming that all farms are laid out in a rectangular grid and that grain production is uniform throughout the rectangle. Each of these grids was 5 square kilometers in size. The study used geo-coding in conjunction with grain production density maps to establish a grain density grid surrounding each of the elevator locations. Trimac mathematically determined that the average length of haul, in terms of kilometers, for each truck was equal to the equation (¼ X + ¼ Y), where x and y are east-west and north-south distances on the grid. The graphical illustration of this calculation is shown in Figure 2.2.

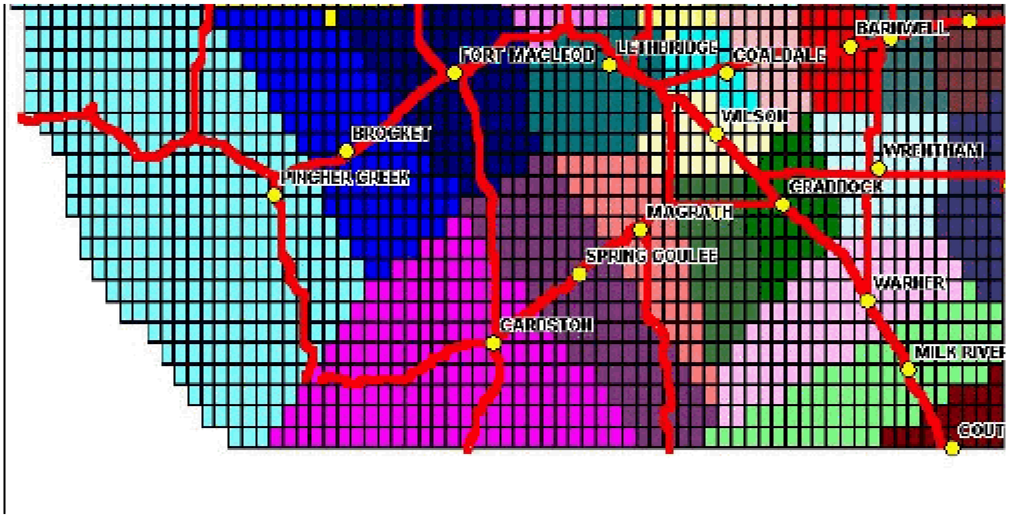


Source: Trimac (1999).

Figure 2.2: Farm to Elevator Trucking Distance on a North-South / East-West Grid

The study concluded that the equation (¼ X + ¼ Y) could be used to calculate average length of haul for grain trucks only if the road network was a complete grid. The study suggested the equation becomes flawed when diagonal routes or natural obstacles such as lakes or rivers exist.

The study then created delivery "hinterlands" (delivery zones) based on the crop density grids and the above equation (Trimac, 1999). This process was completed using geo-coding software. Figure 2.3 shows the delivery zones for a set of elevators in Western Canada.



Source: Trimac (1999).

Figure 2.3: Sample Hinterlands Developed using Arc GIS

The study concluded that the average length of haul was largely dependent upon the number of elevators present in a region. The study also concluded that consolidation of the elevator industry in Canada would add approximately 34 million truck-km to the road system and increase the average length of haul by 81% (Trimac, 1999).

3. INFRASTRUCTURE DATA AND MODEL DEVELOPMENT

3.1 Overview

This section discusses the data sources, key assumptions and model development for determining the infrastructure impacts that the cellulosic biofuel industry likely will impose on the Indiana road network. Indiana county level data is used where possible. Data regarding ideal cellulosic plant locations, biomass availability per county, road class usage, and road grids within a particular fuelshed will be combined with key assumptions in an Excel model to determine the infrastructure impacts of a particular cellulosic plant.

3.2 Plant Locations

The actual physical locations of future cellulosic biofuel plants will greatly influence the impact that they have on the surrounding local infrastructure. Because there are currently no commercial cellulosic biofuel plants in the production or construction phases in Indiana, future plant locations must be predicted. It is assumed that cellulosic biofuel plants will be located in areas with extremely high biomass densities, thus reducing the effective radius of the fuelshed required for a particular plant to run at full capacity. A smaller fuelshed will lead to lower biomass transportation costs, thus making the plant more profitable.

The ideal cellulosic plant locations were estimated for Indiana using a cost minimization GAMS linear program model, developed by David Perkis, a Purdue University PhD candidate (Perkis, 2008). The infrastructure impact estimations found in this thesis build on the work of Perkis. The remainder of this section will discuss the assumptions, and data used to derive the ideal plant location

3.2.1 Plant Location Assumptions

Perkis estimated the top nine ideal plant locations in Indiana using a sequential cost minimization approach. That is, plant one first chooses the ideal location in Indiana, then plant two chooses the 2nd most ideal plant location in Indiana, with the knowledge of plant one’s location which influences available biomass supply. In order to derive the plant locations, the following assumptions were made:

1. Each of Indiana's 92 counties could have at most one cellulosic biofuel plant. The plants were located at the county seat.
2. Each cellulosic plant will be capable of utilizing either corn stover, switchgrass or a combination of the two without incurring additional operating costs for enzymes.
3. Construction and operating costs were assumed to be the same for each plant, with biomass acquisition being the only variable cost. Total biomass costs are comprised of the actual cost of the biomass (a differential exists between switchgrass and corn stover) plus a variable biomass transportation expense. Biomass transportation expenses were calculated based on distances between county seats.
4. Ideal plant locations were determined in sequential order. The first plant developed within a fuelshed had first access to the available biomass and subsequent plants had full knowledge that they could not access biomass that was being used by the first plant in the fuelshed.
5. Each plant has a capacity to produce 50 million gallons of biofuel per year.
6. Available biomass was determined from the 'billion ton study' data of biomass availability on a county level basis (Perlack et al. 2005). In addition, Perkis used the biomass availability assumptions in Table 3.1 to establish the final density of convertible biomass within each county.

Table 3.1: Biomass Availability Assumptions for Ideal Plant Locations

Sustainable Removal Rate (%)	52.5%
Farmer Participation (%)	75.0%
Storage Loss (%)	8.4%
Biofuel Yield for Corn Stover (gal/ton)	69.70
Biofuel Yield for Switchgrass (gal/ton)	67.65

Source: Perkis, (2008).

3.2.2 Ideal Plant Locations

The cost minimization model then ranked each of the 92 Indiana counties in terms of total biomass cost and biomass type utilization. Each plant could choose to either utilize corn stover, switchgrass or a combination of the two feedstuffs to produce the 50 million gallons of biofuel. As shown in Table 3.2, the model indicated that the top 4 ideal plant locations in Indiana would produce biofuels solely from corn stover.

Table 3.2: Biomass Selection for Plant Location Cost Minimization

		% of Biofuel Derived from Biomass Type	
Plant	Total Biomass Cost per saleable gal.	Corn Stover	Switchgrass
1	$ 0.55	100%	0%
2	$ 0.57	100%	0%
3	$ 0.58	100%	0%
4	$ 0.65	100%	0%
5	$ 0.84	9%	91%
6	$ 0.85	7%	93%
7	$ 0.86	0%	100%
8	$ 0.89	0%	100%
9	$ 1.00	0%	100%

Source: Perkis, (2008).

The model established that the most profitable cellulosic biofuel plants would utilize corn stover as the primary feedstuff to produce biofuels and be concentrated in North Central Indiana. Figure 3.1 shows the top 9 least cost plant locations in Indiana based on the biomass cost minimization approach.

Figure 3.1: Projected Most Profitable Cellulosic Plant Locations in Indiana

3.3 Fuelshed Development

In order to determine the infrastructure impacts of the cellulosic biofuel industry; the available biomass must be estimated to determine the effective fuelshed for a particular cellulosic plant. A fuelshed is simply the area in which a particular cellulosic biofuel plant will source biomass to convert to useable biofuels. This thesis utilized the GIS software application ArcMap, biomass data from the Oak Ridge Laboratory, and the ideal plant location data from Perkis to establish each plant's fuelshed.

3.3.1 County Level Biomass Supply

Data for the available biomass within each of the 92 Indiana counties was obtained from the Oak Ridge Laboratory "billion ton study" (Perlack et al. 2005). The study estimated the supply of corn stover and switchgrass in terms of dry tons on a county level basis. It was assumed that corn stover and switchgrass were being produced on separate tracks of land, thus the summation of available corn stover and switchgrass represented the total available biomass for a given county. In addition to biomass supply estimations for corn stover and switchgrass, the “billion ton study” estimated the available corn stover supply under three scenarios: current tillage, more land in no till, and all land in no till. Because future farming practices are unknown, this thesis used the supply estimations for ‘current tillage’ as it would represent the worst case scenario in terms of supply availability. If farming practices continue to shift towards a no-till system for corn production, then the levels of available corn stover are likely to increase within a given county.

The Oak Ridge Laboratory data was then altered to represent more localized estimations of the Indiana sustainable removal rates, farmer participation, and storage losses. The following is a more detailed explanation of each of the variables:

- Sustainable removal rate: The sustainable removal rate is the percentage of the total available biomass that can be removed, taking into account both technical feasibility issues and environmental constraints. This thesis will utilize the minimum and median estimations, 38 percent and 52.5 percent, of the Brechbill & Tyner’s study (Brecbill & Tyner, 2008). Examples of factors that influence sustainable removal rates include: baling method, soil fertility, soil type and slope, and weather conditions.
- Farmer participation: Farmer participation is the percentage of all farmers within a given fuelshed that will actually be willing to provide biomass to the cellulosic plant. It is assumed that the willingness of farmer participation will not be influenced by farm size, thus a 50 percent farmer participation rate would mean that only 50 percent of the biomass within a given area is actually available for biofuel conversion. This study will examine the impacts of a 75 percent farmer participation in the first scenario and 50 percent farmer participation in scenario two.
- Storage loss: The storage loss represents the average amount of biomass that is lost from the time the biomass is harvested until it is actually utilized in the cellulosic biofuel plant. Loss occurs from transportation and weather elements. Brechbill & Tyner estimated that the storage loss for biomass is approximately 8.4 percent (Brechbill & Tyner, 2008)

Table 3.3 shows assumptions for sustainable removal rates, farmer participation and storage loss that were used in this study. Scenario one represents the 'most likely' case while scenario two represents the 'worst case' scenario in terms of sustainable removal rate and farmer participation.

Table 3.3: Biomass Supply Assumptions

	Scenario 1	Scenario 2
Sustainable Removal Rate (%)	52.5%	38.0%
Farmer Participation (%)	75.0%	50.0%
Storage Loss (%)	8.4%	8.4%

Source: Brechbill (2008).

3.3.2 Biofuel Density

In order to determine the actual fuelshed that each of the cellulosic plants will require, the biomass supply data must be converted from biomass tons per county to biofuel density. Biofuel density is simply the amount of biofuel that can be produced in a given square mile of land. The following equation represents the conversion of biomass tons per county to biofuel density:

$$\text{Biofuel Density} = \left[\frac{T \times S \times F \times (1 - L)}{M}\right] \times \text{Yield}$$

where T is the Oak Ridge Laboratory estimated total dry tons of biomass per county, S is the sustainable removal rate, F is the farmer participation level, L is the storage loss, M is the square miles in a given county and Yield is the gallons of biofuel produced per dry ton of biomass. The original Oak Ridge Laboratory data assumes that the sustainable removal rate is 75%. Thus, the effective sustainable removal rate for Indiana is determined by the following equation:

$$S = \frac{\text{Indiana Sustaibable Removal Rate}}{.75}$$

Biofuel yield estimates vary based on production type and feedstuff source. Table 3.4 shows various estimations for biomass yield.

Table 3.4: Biomass Yield Estimations

Conversion Process	Yield (gal./ton)	Source
Biochemical	62.3	Sheehan et al, 2004
Biochemical	69.7	Tiffany, 2007
Biochemical	89.7	Bain, 2007
Thermochemical	80.1	Bain, 2007
Thermochemical	61.35	Wright & Brown, 2007

It should be noted that the literature reports expected biomass yields ranging from 55 gallons per ton to 110 gallons per ton. This research utilized Tiffany's estimate of 69.7 gallons of biofuel per ton for corn stover and was adjusted for the BTU difference for switchgrass (Tiffany, 2007).

County level area data from the U.S. Census Bureau was then used to convert the biomass supply data to gallons of biomass per square mile (biofuel density). The U.S. Census Bureau reports the number of square miles for each county in Indiana (U.S. Census, 2009). The data was not adjusted to account for streams, rivers, or other non-arable land. Table 3.5 shows an example of the conversion of biomass supply to biofuel density for five Indiana counties.

3.3.3 GIS ArcMap

GIS ArcMap version 9.2 was used to determine the physical fuelsheds surrounding the top three most ideal plant locations in Indiana. The first step is to calculate the area in each county, in terms of square miles, that is located within given distances of a specific cellulosic plant. This step is needed as the biofuel density data established in section 3.3.2 is reported on a county level basis. Step two is combining the specific county area within a given distance of the cellulosic plant with the biofuel density in order to establish the fuelshed.

Table 3.5: Example of Conversion of Biomass Supply to Biofuel Density

County	Billion Ton Study	Adjusted Biomass Supply	Gallons Biofuel	Sq. Miles	Biofuel Density
	(dry tons)	(dry tons)	(gallons)	(sq. miles)	(gal/sq. mile)
Adams	101,742	48,928	3,410,267	339	10,049
Allen	137,099	65,931	4,595,396	657	6,992
Bartholomew	43,635	20,984	1,462,597	407	3,595
Benton	211,258	101,594	7,081,107	406	17,428
Blackford	35,311	16,981	1,183,587	165	7,169

Source: Author's Calculations (2009).

3.3.3.1 County Area Calculation

To establish the projected fuelshed for a particular plant, the area in square miles that exists within specified distances of a plant must be known on a county level basis. In order to determine county level area within a specific distance of a plant, this thesis used Arc GIS and followed a methodology similar to the Brecbill & Tyner study. A major difference between this thesis and the biomass supply section of the Brecbill & Tyner study is that the top three ideal cellulosic plant locations have overlapping fuelsheds. This is likely to occur because cellulosic plants will attempt to locate in areas of dense, cheap biomass. In Indiana, those areas are located in north central Indiana where large amount of corn stover exists. In order to calculate the county level area data to determine an accurate fuelshed for each of the 3 cellulosic plants examined, the following assumptions have been made regarding overlapping biomass collection areas:

- The cellulosic plants will have biomass supply priority based on the sequential order of being built. For example, if the fuelsheds for plant 1 and plant 2 overlap, then plant 1 has the first opportunity to contract with farmers' for biomass supply. If plant 2 and plant 3 have overlapping fuelsheds, plant 2 will have priority over plant 3 for biomass supply. It is assumed that the fuelsheds will remain fixed over the life of the cellulosic plant and that farmer's will not supply an alternative cellulosic plant once an initial contract was made even if a subsequent plant is built closer to the farmer.

- In this analysis, portions of fuelsheds are outside the state of Indiana. It is assumed that the biomass supply in these out-of-state counties is equivalent to the supply in the bordering Indiana counties.
- The initial cellulosic plant locations were based on the data in scenario 1 (Perkis, 2008). This analysis assumes that the plant locations do not change when the fuelsheds are determined based on scenario 2 assumptions. Thus, this study assumes that investors and/or industry decide on the ideal plant locations based on the initial assumptions and any alternations to farmer participation, clearance rates, biomass supply, and biofuel yield are made after a plant has been built (thus unable to relocate).

To begin the actual area calculation, the longitude and latitude coordinates for each the projected specific ideal plant locations were entered into the GIS software. The latitude and longitude coordinates are the coordinates of the county seat for the each of the counties studied. The county seat was used for the cost minimization and subsequent infrastructure impact analysis because the county seat is usually located in the center of a county and allows for consistent transportation distance estimations. It should be noted that it is highly unlikely that the future cellulosic plants will be physically located in the center of the county seat as these areas are normally highly populated; rather, the plants will likely choose to locate closer to the physical biomass, but the difference should be small. The specific coordinate data represents the projected physical location of a cellulosic plant. The coordinates are used to establish a reference point in which concentric circles are drawn around the plant to estimate the area, in square miles, that is required to supply the required biomass for biofuel conversion. The specific coordinate data used in this thesis are in Table 3.6.

Using the plant location as the starting point, concentric circles are drawn around each plant in 5 mile increments as done in the Brechbill & Tyner study (Brechbill & Tyner, 2008). The area within each county between the concentric circles is then calculated by using the intersect tool. For example, Figure 3.2 shows a close-up view of plant 1 which is located in White county. The dot in the center of the map represents the projected cellulosic plant location. Two rings are shown surrounding the plant, one with a 5 mile radius and second which has a 10 mile radius. The circles intersect two counties with the largest portion being White County and Carroll County located on the bottom-right portion of the map. It should be noted that in this example there is not an overlapping fuelshed from another plant.

Table 3.6: Cellulosic Plant Specific Locations

Plant	County	County Seat	Latitude	Longitude
1	White	Monticello	40° 44′ 48″ N	86° 45′ 55″ W
2	Tipton	Tipton	40° 17′ 6″ N	86° 2′ 25″ W
3	Marshall	Plymouth	41° 20′ 38″ N	86° 18′ 45″ W

(Source: GeoHack (2008).

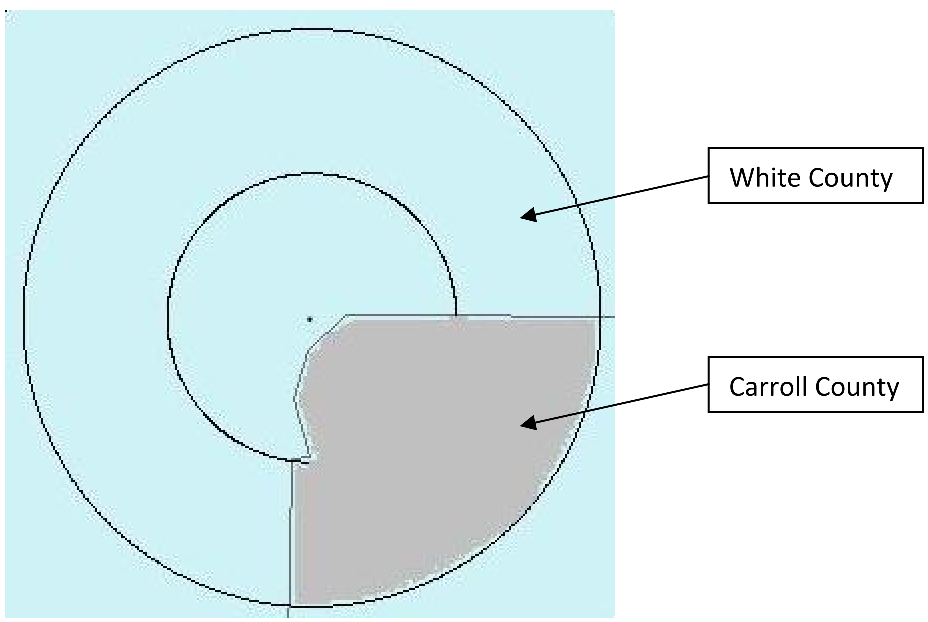


Figure 3.2: Sample Area Calculation

To establish the area distribution between White county, and Carroll County in Figure 3.2, the intersect tool is used. First, the intersect tool is used to calculate the distribution of area by county within the 5 mile concentric circle; that is, the number of square miles that fall within White County, and the number of square miles that falls within Carroll County within 0 to 5 miles of plant 1. Looking at Table 3.7 we can see that 20.5 square miles of the 5 mile concentric circle fall within Carroll County and that 58.1 square miles fall within White County.

Table 3.7: Area within Counties for Given Buffer Zones

	Distance from Cellulosic Plant (miles)	
County	0 to 5 miles	0 to 10 miles
Carroll	20.5	82.4
White	58.1	230.8
Total	78.6	313.2

Source: Author's Calculations (2009).

The same process is used for the 10 mile concentric circle which now includes the area 0 to 5 miles from the plant and the area 6 to 10 miles from the plant. In order to calculate the number of square miles that fall within White County between the 5 and 10 mile circles, the number of square miles in White County within the 0 to 5 mile distance is subtracted from the number of square miles in White County within 0 to 10 miles of plant 1. For example, 230.8 of the square miles that make up the 10 mile concentric circle fall within White County. However, 58.1 of those square miles fall within the 5 mile concentric circle, thus only 172.7 square miles fall within White County and the 5 and 10 mile concentric circles.

Calculating the physical area within each county for areas that have overlapping fuelsheds follows the methodology stated above but uses the intersect tool one more time to establish area credit to the first plant that was built. For example Table 3.8 shows a hypothetical example where plants 1 and 2 have overlapping 5 mile concentric circles.

Using the intersect tool it was established that 20.5 square miles of Carroll county are located within 5 miles of plant 1 and 22.5 square miles of Carroll are located within 5 miles of plant 2. To calculate the overlapping area, the intersect tool was used to determine the area where just Carroll county, the 5 mile buffer for plant 1 and the 5 mile buffer for plant 2 intersect. In this example 17.5 square miles are in the overlap area.

The area is then allocated to the plant based on sequential order, thus plant 1 is credited 20.5 square miles of Carroll County, and plant 2 is credited 5 square miles of Carroll county based on the following equation:

$$\text{Carroll County Area} = \text{Plant 2 area} - \text{Plant 1 and Plant 2 Overlap}$$

Table 3.8: Sample Overlapping Fuelshed's

	Area (sq. miles)		
County	Plant 1	Plant 2	Plant 1 and 2 overlap
Carroll	20.5	22.5	17.5

Source: Author's Calculations (2009).

3.3.3.2 Fuelshed Development

Combining the county area data established by the ARC GIS software and the biofuel density data from section 3.3.2, the required fuelshed for each of the top 3 cellulosic plants is established using the following equation:

$$50{,}000{,}000\ \text{Gal.} = \left[\left(\left(\frac{D_5}{M}\right) \times (C_5 - C_0)\right) + \left(\left(\frac{D_{10}}{M}\right) \times (C_{10} - C_5)\right) \ldots + \left(\left(\frac{D_x}{M}\right) \times (C_x - C_{(x-5)})\right)\right]$$

where D is weighted average of the gallons of biofuel produced within the counties that intersect the concentric circle , M is square miles, and C are square miles of biomass available within the specific buffer zone. In simple terms, this equation simply adds the number of gallons supplied to the plant by each county within a given concentric circle of the plant to the point where the cellulosic plant demand is satisfied. Thus to determine when the summation of the number of gallons of biofuel supplied by each county within a given distance of the plant equals the required 50 million gallons, the equation must be solved for x.

$$x = \left[\frac{50{,}000{,}000\ \text{Gal.} - \left[\left(\left(\frac{D_5}{M}\right) \times (C_5 - C_0)\right) + \left(\left(\frac{D_{10}}{M}\right) \times (C_{10} - C_5)\right)\right]}{\left(\frac{D_x}{M}\right)}\right]$$

Solving for X establishes the distance (radius) an individual cellulosic plant will have to go to source the required biomass in order to run at capacity. It is assumed that this distance is uniform surrounding an individual plant with the exception of areas where overlapping fuelsheds exists.

3.4 Model Development

Each truck that delivers biomass to a cellulosic plant has an impact on the local road infrastructure. This section of the chapter will provide the data and methodology used to determine the number of truckloads needed for each plant, average length of haul (LOH), one-way annual tuck miles (VTM) and road class usages.

3.4.1 Truckloads

This thesis assumes that all trucks transporting biomass to one of the three analyzed cellulosic facilities will each carry 26 round bales of biomass. Brechbill & Tyner suggest that 26 bales each weighing .5 tons, thus 13 total tons, would be the maximum capacity that each truck can safely transport (Brechbill & Tyner, 2008). To determine the number of trucks needed to supply the biomass for a given plant the following equation is used:

$$\text{Truckloads} = \left(\frac{\text{Plant Capacity}}{\text{Biomass Yield} \times \text{Truck Capacity}}\right)$$

Each plant would need approximately 55,182 semi truck deliveries per year to provide an adequate supply of biomass to run at the 50 million gallon plant capacity. In other words this means that each cellulosic plant will need to have a truck delivery every 9.52 minutes, 365 days per year.

3.4.2 One-way Annual Truck Miles & Average Length of Haul

An important measure of road infrastructure impact is the number of loaded miles that are being traveled on a specific set of roads. One-way annual truck miles (VTM) are the total number of miles driven by the trucks delivering biomass to the cellulosic facilities. VTM's are determined based on the location of the biomass relative to the location of the cellulosic plant, thus the distance the trucks need to travel to deliver biomass. In order to determine the VTM, the number of truck loads between within each buffer zone is calculated. The 55,182 trucks that are needed to supply biomass to each cellulosic plant are divided into their buffer of origin. For example Table 3.9 shows the number of available tons that are contracted to go to Plant 1 within 0 to 5 miles of the plant. The area between two concentric circles will be referred to as a buffer zone. For example, the area between the 0 and 5 mile concentric circles is referred to as the 5 mile buffer zone. To transport the 23,504 tons of available biomass within the 5 miles of the plant, 1,808 truck trips are needed. Thus, 1,808 trucks originate their trip within the 5 mile buffer zone.

Table 3.9: Buffer Zone Located Between 0 and 5 Mile Concentric Circles

County	Available Biomass	Truckloads Needed	VTM
	(tons)	(# of trucks)	(miles)
Carroll	5,460	420	1,779
White	18,044	1,388	5,880
Total	23,504	1,808	7,659

Source: Author's Calculations (2009).

The VTM is then calculated by using the following equation:

$$VTM = \text{circuity factor} \times \left[\left(T \times \sqrt{\left(\frac{\left(\left(\frac{(A_5 - A_0)}{2}\right) + A_0\right)}{\pi}\right)}\right) + \cdots \left(T \times \sqrt{\left(\frac{\left(\left(\frac{(A_X - A_{X-5})}{2}\right) + A_{X-5}\right)}{\pi}\right)}\right)\right]$$

where T is the number of trucks that originate within the corresponding buffer zone, A is the area within the concentric circle and the circuitry factor is the correction for non-direct road routes. The circuitry factor in this analysis is 1.2 which means that 20% of the VTM are for trucks traveling on roads that do not lead directly to the cellulosic plant (Quear, 2008). This analysis assumes that the biomass is evenly distributed within a specific buffer zone. The average truck will travel the distance above the lower bound and below the upper bound required to service half of the square miles within a buffer distance. Referring to Table 3.9, the 5 mile buffer represents the distance 0 to 5 miles from Plant 1. Thus, the average distance of biomass origination is 3.53 miles. Multiplying the 1,808 trucks that are needed to transport the biomass by the average distance of 3.53 miles and the circuitry factor of 1.2, the total VTM for this buffer zone is 7,659 miles. This process is repeated for each the buffer zones surrounding a particular cellulosic plant, and the summation of the VTM's within each buffer zone represents the total road infrastructure impact for that plant.

The average number of miles for each truck delivering biomass to a cellulosic plant is referred to as the average length of haul (LOH). LOH is determined based on the following equation:

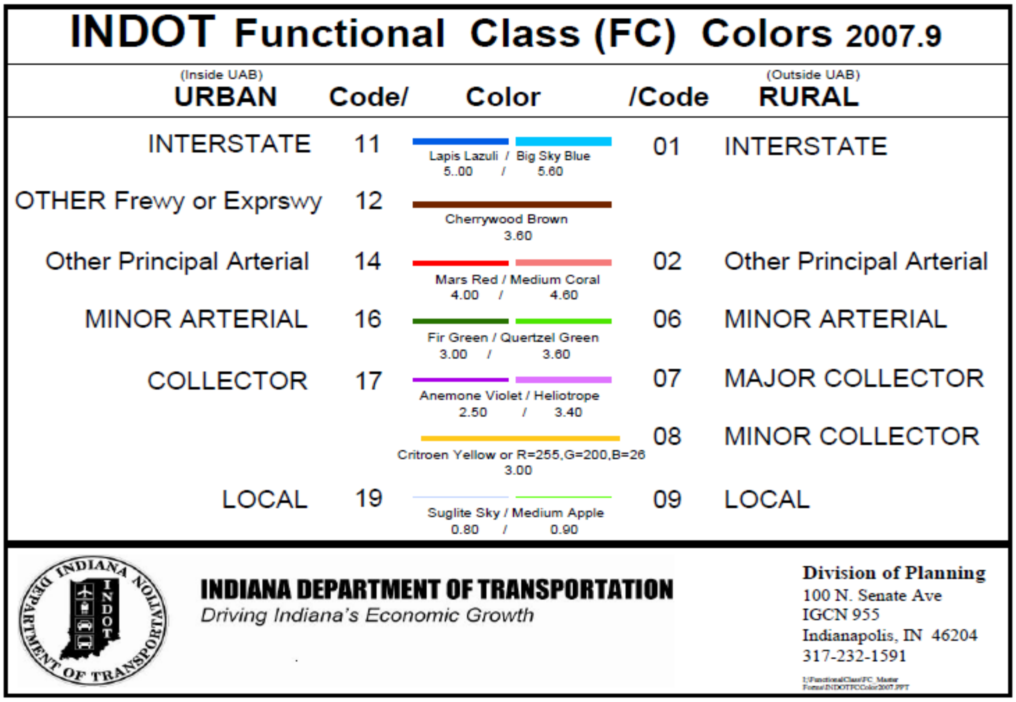
$$\mathrm{LOH} = \frac{\mathrm{VTM}}{\mathrm{Truckloads}}$$

(Source: Quear, 2008)

where VTM is the total VTM for a given plant and truckloads are the total truckloads delivered to a plant per year.

3.4.3 Road Class Usage

To obtain a better idea of the type of roads that will be used for biomass delivery, this section outlines the methodology and data used to calculate the VTM based on functional road class (FC). Indiana roadways are classified based on whether the section of roadway is located in rural or urban areas, if it is a federal interstate, and the overall level of traffic that occurs. The Indiana Department of Transportation (INDOT) ranks Indiana roads on a scale of 1 to 11 as in Figure 3.3 (Indiana Department of Transportation, 2007). The right side of the figure shows the roads that are classified as rural roads while the left side shows urban roads. The level of traffic is the highest for the roads at the top of the figure, and traffic decreases as the numbers increase. For example, the highest traveled rural roads are 01 Interstates, and the lowest traveled rural roads are 09 Local roads.



Source: INDOT (2008).

Figure 3.3: INDOT Functional Road Classes

Using data from the Federal Highway Administration's (FHA) vehicle travel information system (VTRIS), this thesis estimates the FC of roads that will receive the most travel within each of the fuelsheds. The VTRIS is a vehicle monitoring program that attempts to estimate traffic for various types of vehicles on various types of roadways throughout the country. VTRIS reports both current and historical average daily counts of 5-axle semi trucks for each of the Indiana road classes. Table 3.10 shows the estimated average daily 5-axle truck traffic count in Indiana for 2008. For example, on average, 3,125 trucks are counted on rural principal interstates (FC 1) each day (Federal Highway, 2009).

Note that the vehicle counts represent data from both fixed stations and portable counting devices and do not represent the total daily truck traffic on Indiana roadways. However, with portable counting devices being spread randomly throughout the state on all road types, the data does give an indication of the relative truck travel across road class types. In order to compare the average truck counts across road classes, the total miles of roadway for each road class in Indiana was determined using Arc GIS. The average daily trucks per mile indicated in Table 3.10 is the number of observed trucks that travel on each mile of a particular road class in Indiana. For example, 3,125 trucks are observed on average on FC 1 roadways. There are 1,042 miles of FC 1 roads in the state of Indiana so the average daily trucks per mile of FC 1 is simply the daily truck count divided by the total FC miles, thus, 2.99 daily trucks per mile.

Table 3.10: 2008 Functional Road Class usage in Indiana for 5-axle Trucks

Road Classification (FC)	Description	Average Daily Truck Count	Road Miles	Average Daily Trucks per Mile
		(# trucks)	(miles)	(trucks/mile)
1	Rural Principal Arterial Interstate	3125	1,042	2.999
2	Rural Principal Arterial Other	467	1,867	0.250
6	Rural Minor Arterial	123	2,374	0.052
7	Rural Major Collector	51	10,909	0.005
11	Urban Principal Arterial Interstate	4291	332	12.922
12	Urban Principal Arterial Other Freeways	564	134	4.204
14	Urban Principal Arterial Other	284	1,433	0.198
16	Urban Minor Arterial	109	1,030	0.106
17	Urban Collector	0	202	0.000

Source: Author's Calculations based on Federal Highway (2009).

Arc GIS was then used to determine the actual road classes and the number of total road miles that exist within each of the buffer zones. Looking at Figure 3.4, the Plant 1 fuelshed is overlaid with the road infrastructure data provided by the Indiana Department of Transportation (Indiana Department of Transportation, 2004). Using the intersect tool as done in section 3.3.3.1, the number of miles of each road classification was determined for each of the buffer zones.

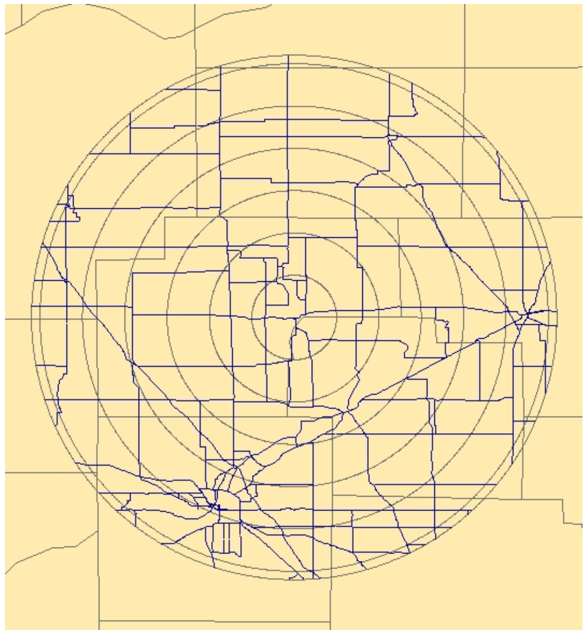


Figure 3.4: White County Fuelshed with Road Infrastructure

First, the intersect tool was used to isolate the roadways that exist within the confines of the concentric circles. The road name, road length in miles, functional road class, and proximity to the cellulosic plant for each data entry was then exported to excel. The exported data indicates the number of miles for each road class within a given distance of the cellulosic plant but does not directly indicate the number of roadway miles for each class within a given buffer distance. For example, Table 3.11 shows the number of miles for each road class within 10 miles of the White County plant. There are 6.92 miles of 02 Principle Arterial roadways within 5 miles of the plant location and 31.11 miles within 10 miles of the plant. To determine the number of miles within 5 to 10 miles of the plant (10 mile buffer zone), the miles within the 5 mile concentric circle (6.92) are subtracted from the miles within the 10 mile concentric circle (31.11). Thus 24.19 miles of 02 Principle Arterial roads exist within 5 to 10 miles of the White County plant location. This process is repeated for each of the buffer distances and for each of the plants under both scenarios. If there is an overlapping area, then the miles are given to the plant that was built first, thus the same methodology as discussed in biomass supply.

Table 3.11: Road Miles by Functional Road Class for White County Plant Location

	Distance (miles)	
Road Class	5	10
2	6.92	31.11
6	4.39	11.2
7	31.96	117.35
8	1.05	1.05
9	0	0.51
14	4.22	4.22
16	1.37	1.37
17	1.02	1.02
Total	50.93	167.83

Source: Author's Calculations (2009).

In order to determine the proportion of roadway use by FC, the average daily truck per mile data is combined with the roadway miles by FC within each of the fuelsheds to determine a weighted average by using the following equation:

$$100 = A\ [(T_1 \times M_1) + \cdots (T_2 \times M_2)]$$

where A is an adjustment factor that is used to adjust the actual miles of a FC within a buffer zone compared to the total miles of a FC within the state, T is the trucks per mile for each FC, and M is the miles of FC within a particular buffer zone. The equation is then solved for A using the following equation:

$$A = \frac{100}{[(T_1 \times M_1) + \cdots (T_2 \times M_2)]}$$

The adjustment factor is then multiplied by the T and M for each FC class to determine the percentage of the VTM within the particular buffer zone that are projected to be traveled on that FC. For example, Table 3.12 shows data from the 10 mile buffer zone for Plant 1. The table indicates that only 3 types of road classes fall within this specific buffer zone, FC 2, FC 3 and FC 7. The average daily trucks per mile represent the truck observation data divided by the total miles of FC within the state. Note that the truck per mile ratio remains constant regardless of plant location or buffer distance as this is a statewide calculation. The miles of FC in the buffer zone are the actual number of roadway miles that are present in that particular buffer zone surrounding the plant. In this example, there are 24.2 miles of FC 2 and total of 116.4 miles of all roadways within the 10 mile buffer zone. The numbers are then adjusted using the adjustment factor as calculated in the previous equation. By multiplying the adjustment factor by T and M, the weighted percentage by FC is established. For example, the weighted FC for road class 2 is calculated by multiplying T (.25), M (24.2) and A (14.7) to establish a weighted average of 89 percent.

Table 3.12: Functional Road Class Percentage for 10 Mile Buffer Zone

Road Class	Daily Trucks per Mile (T)	Miles of FC (M)	Adjustment Factor (A)	Weighted FC (Portion of VTM by FC)
	(trucks/mile)	(miles)		%
2	.25	24.2	14.7	89%
6	.05	6.8	14.7	5%
7	.0047	85.4	14.7	6%
Total	116.4			100%

Source: Author's Calculations (2009).

The total VTM per functional road class for each plant is calculated by multiplying the number of miles that travel through each buffer zone, the weighted functional class percentage as determined in Table 3.12, and the circuitry factor of 1.2. The trucks that collect biomass within a buffer zone have to travel through other buffer zones in order to reach the cellulosic plant (except if starting 0 to 5 miles from plant). As the trucks travel from zone to zone, the available road types change, thus forcing trucks to switch roads. The actual VTM's traveled within each buffer zone are a combination of VTM's from trucks originating in that buffer zone and from the trucks that had to pass through the buffer in route to the cellulosic plant. Table 3.13 shows an example of the calculation of VTM for the White County plant. There are 5,408 trucks that originate within 5 to 10 miles of the plant. The VTM for the trucks originating within the 10 miles buffer zone are calculated by multiplying the trucks (5,408) by the average distance traveled within that buffer zone (2.906) and circuitry factor (1.2). Thus, 18,857 VTM are traveled in the 10 mile buffer zone from the trucks collecting biomass within 6 to 10 miles of the plant. In addition, 47,978 trucks will pass through the 10 mile buffer zone in-route to the cellulosic plant. These trucks will travel the full 5 miles through the buffer zone, thus the total VTM's are calculated by multiplying the trucks (47,978), distance in buffer zone (5 miles) and the circuitry factor (1.2) for a total of 287,868 VTM's. In this example, the total VTM's within the 10 mile buffer zone are 306,725.

Table 3.13: VTM calculation with Incoming Trucks

	Buffer Distance (Miles)	
	5 to 10	10 to 31
Trucks	5,408	47,978
VTM from Trucks in buffer	18,857	-
VTM from Inbound trucks	287,868	-
Total	306,725	-

Source: Author's Calculations (2009).

VTM by FC is determined by multiplying the VTM within the buffer zone by the weighted FC percentage. Table 3.14 shows the data was determined above for the 10 mile buffer zone for the White County plant. For example, to determine the VTM's for FC 2 within the 10 mile buffer zone, the weighted FC (89%) is multiplied by the total VTM within the buffer zone (306,725) for a total of 272,985 VTM. In simple terms, trucks prefer to travel on larger, better maintained roadways as indicated in the truck observation data. Thus, even though more miles of FC 7 exist within the 10 mile buffer compared to FC 2, trucks will travel more miles on the larger FC 2 roadway.

Table 3.14: Example of Establishment of VTM for White County

Road Class	Weighted FC	VTM	FC Distribution
	(%)	(miles)	(miles)
2	89%	306,725	272,985
6	5%	306,725	15,336
7	6%	306,725	18,403
Total	100%		306,725

Source: Author’s Calculations (2009).

4. INFRASTRUCTURE IMPACT RESULTS

4.1 Overview

Because the cellulosic biofuel industry is still in its infant stages, the number of possible scenarios regarding future plant location, biomass supply and infrastructure impacts are endless. This research takes a case study approach to estimate the most likely infrastructure impacts if a cellulosic biofuel industry develops in Indiana. This section provides estimates of the infrastructure impacts of the top three most ideal plant locations. The projected infrastructure impacts in terms of vehicle trip miles (VTM) and truckloads are estimated for each case study site.

Results are provided for two scenarios regarding sustainable biomass removal rates, farmer participation, storage losses and biofuel yield. Scenario 1 represents the most likely scenario while scenario 2 is considered a worst case scenario. The scenarios differ in removal rate and farmer participation rate. In addition, the first two scenarios will be compared against the projected infrastructure impacts of a higher biomass to biofuel yield conversion rate as estimated by NREL (Bain, 2007). Table 4.1 outlines the assumptions made for each of the scenarios.

Table 4.1: Scenario Assumptions

	Scenario 1	Scenario 2	NREL Biofuel Yield
Sustainable Removal Rate (%)	52.5%	38%	52.5%
Farmer Participation (%)	75.0%	50%	75%
Storage Loss (%)	8.4%	8.4%	8.4%
Biofuel Yield from Corn Stover (gal/ton)	69.7	69.7	89.1%

Source: Author's Calculations (2009).

4.2 Biomass Supply

Arc GIS was used in conjunction with the scenario assumptions and the billion ton biomass data in order to determine the biomass supply within a given distance of an individual cellulosic plant. The following section details the estimated biomass supply; in terms of try tons of biomass that is effectively available to a given plant at varying distances. The data supplied in this section are the net dry tons actually supplied, thus overlapping fuelsheds, farmer participation, sustainable removal rates and storage losses have been accounted for.

4.2.1 Scenario 1 Biomass Supply

Figures 5.1, 5.2 and 5.3 show the biomass supply curves for each of the top three cellulosic plants in Indiana. In order to produce 50 million gallons of biofuel per year, each cellulosic plant will need to source approximately 717,360 tons of biomass within a given fuelshed of the plant. Figure 4.1 indicates that the supply of biomass exponentially grows from the 5 mile concentric circle to the 30 mile concentric circle for the first plant built, White County. This is logical as the effective area within the fuelshed grows exponentially because of the radius squared factor in the area calculation. In contrast, Figures 4.2 and 4.3 have relatively linear supply curves, especially at distances of more than 10 miles from the plant. A reason for the linear biomass supply is that as Plant's 2 and 3 increase the size of their fuelsheds, the available biomass proportionally decreases because of contractual obligations to deliver biomass to previously built cellulosic plants. Once the supply curve intersects 717,360 tons, the effective radius of the fuelshed is established.

Source: Author's Calculations (2009).

Figure 4.1: White County Scenario 1 Biomass Supply Curve

Source: Author's Calculations (2009).

Figure 4.2: Tipton County Scenario 1 Biomass Supply Curve

Source: Author's Calculations (2009).

Figure 4.3: Marshall County Scenario 1 Biomass Supply Curve

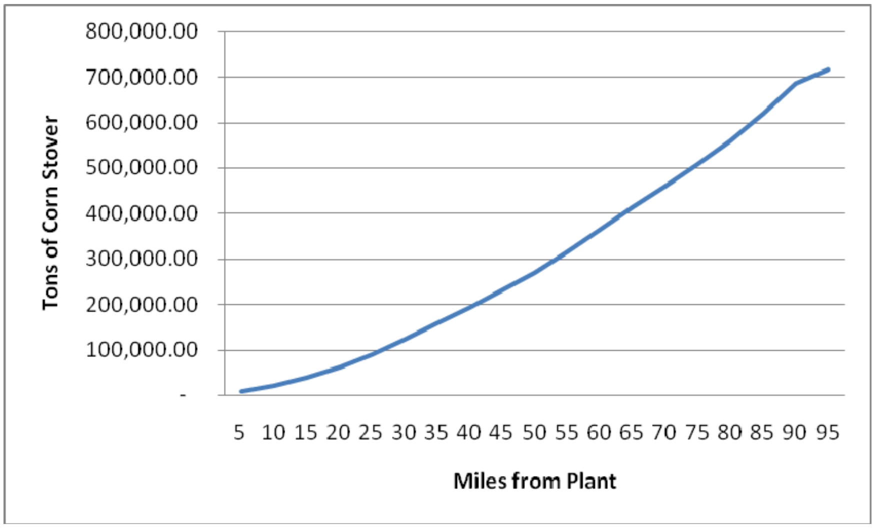
4.2.2 Scenario 2 Biomass Supply

Scenario 2 in essence decreased the available biomass in Indiana by lowering the farmer participation rate and the removal rate from 75 percent to 50 percent and 52.5 percent to 38 percent respectively. In fact, by lowering the farmer participation and removal rates, the available corn stover decreases by 51.7 percent in scenario 2 compared to scenario 1.

After subjecting the biomass data to scenario 2's assumptions, biomass supply curves were calculated and are shown in Figures 4.4, 4.5, and 4.6. Figure 4.4 indicates that under scenario 2, the White County plants available biomass supply is flatter verses scenario 1. This simply means there is less biomass within a given distance of the plant. Figure 4.5 represents the biomass supply for the Tipton County plant under scenario 2. The Tipton plant has much less supply of biomass available especially in the distance of 0 to 30 miles from the plant. The Marshall County cellulosic plant location will be forced to travel up to 100 miles in order collect the 716,134 tons required. It should be noted that 81 percent of the supply for the Marshall County location will need to be sourced from Michigan and Illinois corn producers. The out-of-state supply was assumed to be the same as the available supply in the bordering Indiana counties. However, the data was adjusted by 30 percent to take into account Lake Michigan and the Chicago metro. Figure 4.6 indicts the net biomass supply for the Marshall County after taking into account the out-of-state adjustment.

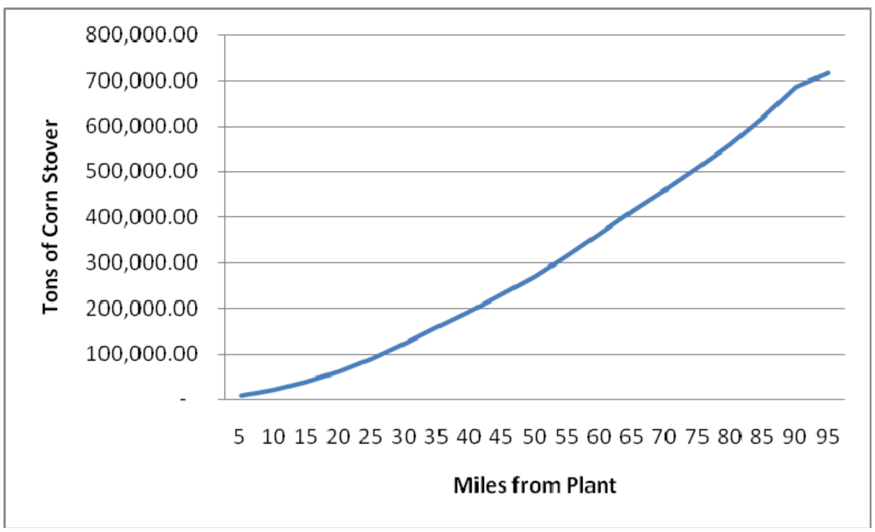
Source: Author's Calculations (2009).

Figure 4.4: White County Scenario 2 Biomass Supply Curve



Source: Author's Calculations (2009).

Figure 4.5: Tipton County Scenario 2 Biomass Supply Curve



Source: Author's Calculations (2009).

Figure 4.6: Marshall County Scenario 2 Biomass Supply Curve

4.3 Projected Fuelsheds

In order to determine the infrastructure impacts of the cellulosic biofuel industry, the fuelsheds were constructed. The effective radius of each fuelshed was determined by using Arc GIS in conjunction with biomass supply data to produce the biomass supply curves in section 3.2.

4.3.1 Scenario 1 Fuelshed's

The fuelsheds for scenario 1 were determined based on the assumptions found in Table 4.1. Each of the three cellulosic plants utilized corn stover for 100 percent of the biofuel conversion. The three cellulosic plants were built in the following order:

1. White County (Plant 1)
2. Tipton County (Plant 2)
3. Marshall County (Plant 3)

Figures 4.7, 4.8, and 4.9 show the projected fuelsheds and locations for each of the plants. Each concentric circle is spaced at 5 miles with the exception of the outer circle which varies based on the specific projected fuelshed radius.

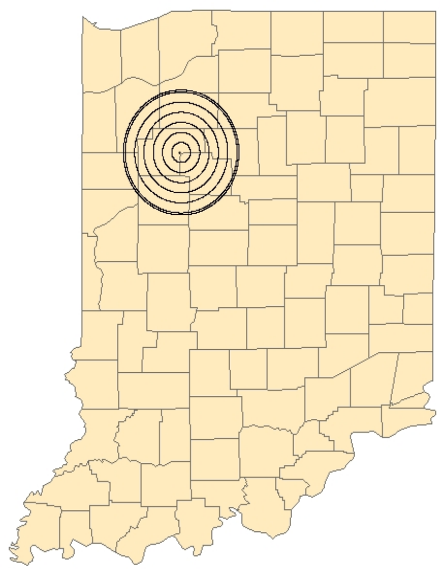


Figure 4.7: White County Scenario 1 Fuelshed

Because the White County plant is projected to be built first, it is able to locate in an extremely dense biomass area, allowing it to shorten truck transportation by sourcing biomass closer to the plant. In addition, the White County plant does not have to take into account the biomass demand competition as do plant's 2 and 3. The combination of locating in the most dense biomass region and avoiding competition allows plant 1 to have the smallest fuelshed. Table 4.2 shows the estimated fuelshed radius for each of the plants. In order to effectively utilize the Arc GIS software, the radius for each fuelshed was rounded to the nearest mile, thus slightly changing the effective amount of biofuel produced by each plant.

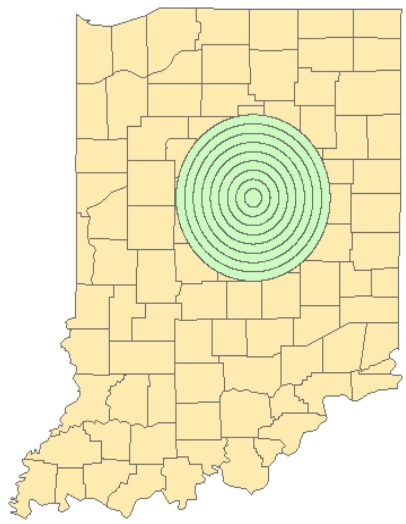


Figure 4.8: Tipton County Scenario 2 Fuelshed

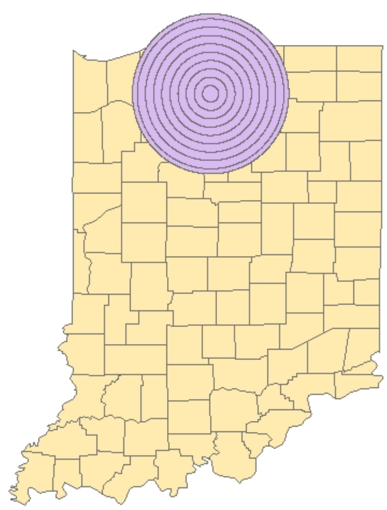


Figure 4.9: Tipton County Scenario 2 Fuelshed

Table 4.2: Projected Fuelshed Radius for Scenario 1

County	Fuelshed Radius (miles)	Area (sq. miles)	Biofuel Produce (gallons)
White County	31	3,019	50,011,364
Tipton County	45	6,362	49,911,717
Marshall County	48	7,238	50,365,338

Source: Author's Calculations (2009).

The White County plant will need to travel 31 miles in order to obtain an adequate supply of corn stover, thus the effective radius of the fuelshed. Plant 2 will need to have a fuelshed of approximately 45 miles in order to source the same amount of corn stover. The Marshall County plant will need to travel up to 48 miles in order to obtain biomass as its fuelshed is greatly distorted because of the overlapping fuelsheds of plant 1 and plant 2. The Marshall County plant will need to travel up to 55 percent further for biomass compared to plant 1. Figure 4.10 shows all three of the cellulosic plant locations and the projected fuelsheds based on sequential order of being built. Notice that the smallest fuelshed (White County), located on the left of the map, covers portions of both the Tipton and Marshall County fuelsheds. The upper fuelshed represents the Marshall County plant. Because it is the last built plant, it loses biomass to both the Tipton and White County plants. In fact, 23 percent of the area within the 48 mile fuelshed for the Marshall County plant is unavailable because the biomass is redirected to Plant's 1 and 2. In addition, 15% of the Marshall County fuelshed is located outside the state of Indiana. It is assumed that the out-of-state counties have the same biomass availability as the bordering counties in Indiana. It also assumed that 10% of the out-of-state area for plant 3 falls within Lake Michigan, thus is unavailable for biomass collection.

4.3.2 Scenario 2 Fuelshed's

The fuesheds for scenario 2 were developed based on the same methodology for scenario 1. It was assumed that the plant locations remained constant from the original cost minimization linear programming model, even though the assumptions regarding farmer participation and removal rates changed. In reality, if the available biomass estimations changed after the first cellulosic plant was built in a region, the subsequent plants would likely re-evaluate the ideal location to build. In addition, it was assumed that the plant still had biomass priority based on the sequential order of being built.

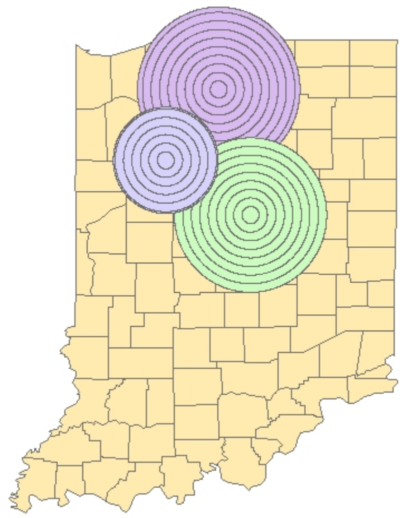


Figure 4.10: Scenario 1 Plant Locations

4.3.3 Scenario 2 Fuelshed's

Figures 4.11, 4.12 and 4.13 represent the estimated fuelsheds for each of the cellulosic plants under the second scenario. The fuelsheds increased for each of the cellulosic plants in scenario 2 because the level of overall available biomass decreased due to lower farmer participation and removal rates. In addition, the fuelsheds for the Tipton and Marshall County plants increased drastically due to overlapping effect of previously built plants. For example, the radius of the fuelshed for White County increased from 31 miles to 48 miles in scenario 2. A large portion of the new fuelshed for Plant 1 was part of the previous fuelshed for Plant 2. Thus, Plant 2's fuelshed must expand in order to compensate for the loss of biomass to Plant 1. Table 4.3 indicates the new fuelshed radius's for each of the cellulosic plants.

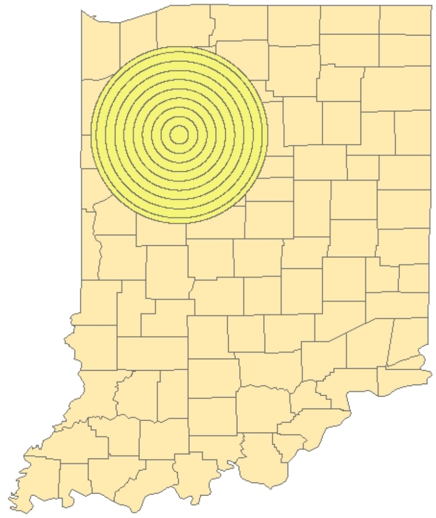


Figure 4.11: White County Scenario 2 Fuelshed

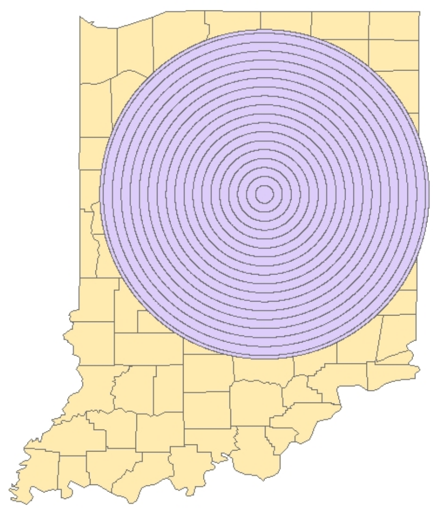


Figure 4.12: Tipton County Scenario 2 Fuelshed

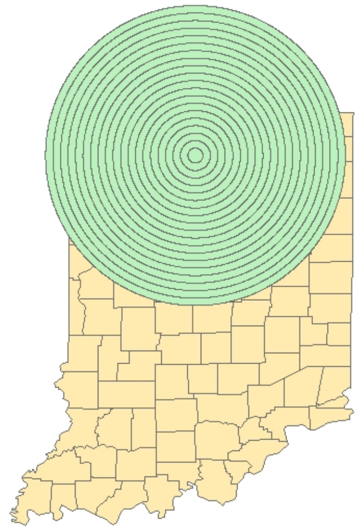


Figure 4.13: Marshall County Scenario 2 Fuelshed

Table 4.3: Projected Fuelshed Radius for Scenario 1

County	Fuelshed Radius (miles)	Area (sq. miles)	Biofuel Produced (gallons)
White County	48	4,534	49,735,035
Tipton County	92	26,577	49,868,744
Marshall County	100	31,400	49,914,561

Source: Author's Calculations (2009).

The White County cellulosic plant will need to travel 48 miles in order to collect an adequate supply of biomass. The Tipton County plant will need to travel up to 92 miles, or 142 percent further than plant 1. The Marshall County location will source biomass up to 100 miles from its location. The Marshall County fuelshed is approximately 163 percent larger in terms of maximum travel distance (radius) compared to plant 1. The larger fuelsheds for Tipton and Marshall Counties are largely due to overlapping fuelsheds. Figure 4.14 shows the fuelsheds for all three plant locations.

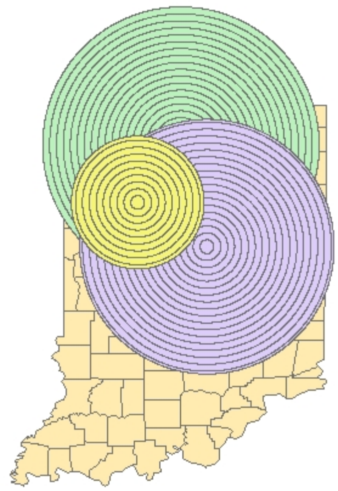


Figure 4.14: Scenario 2 Plant Locations

4.3.4 NREL Yield Estimate Fuelshed

The first two scenarios examined in this case study assumed that the biofuel yield for corn stover was 69.7 gallons per ton. The scenarios differed by altering the farmer participation and removal rates while keeping the yield rate constant. The actual future commercial biofuel yield per ton is extremely uncertain as technology develops. The literature suggests effective yields ranging from 55 to 110 gallons per ton; thus, the actual biofuel yield will significantly affect the size of the fuelsheds for each particular plant. A 2007 NREL study suggested that the biochemical cellulosic process would yield 89.7 gallons per ton on a commercial level (Bain, 2007). Figure 4.15 shows the fuelsheds for each of the plants assuming an 89.7 gallon per ton biomass yield, 52.5 percent removal rate, and 75 percent farmer participation rate. Note that the only assumption that varies in analysis from scenario 1 is the biofuel yield. Figure 4.15 indicates that by increasing the effective biomass yield per ton, the required fuelsheds decrease for each of the plants. In addition, the higher yield allows each of the three analyzed plants to be located in the biomass dense North Central Indiana region having only minimal fuelshed overlap.

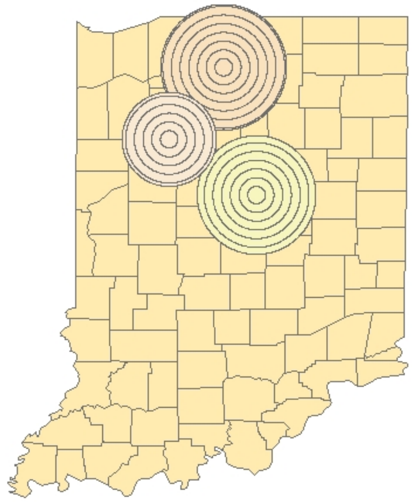


Figure 4.15: Advanced Biofuel Yield Fuelshed

4.3.5 Fuelshed Conclusion

As the effective biomass supply decreases, the fuelsheds will increase for cellulosic plants. Biomass supply can be influenced by crop rotation, farmer participation, removal rates, and weather conditions. In addition, the number of tons of biomass needed for a specific plant will change based on the biomass to biofuel conversion rate, thus decreasing the fuelshed if the yield rate improves or increasing the fuelshed if actual yields are less than anticipated. This case study shows that the average fuelshed radius for scenario 1 is 41 miles, as indicated in Table 4.4. For scenario 2 the radius increases to 80 miles, which is 94 percent larger than scenario 1. By assuming that the actual commercial yield is 89.7 gallons per ton, the effective radius for each plant decreases to an average of 32 miles.

4.4 Infrastructure Impacts

Each truck that delivers biomass to a cellulosic plant has an impact on the local road infrastructure. Cellulosic biofuel production does not produce a saleable by-product such as dried distillers grain as with typical ethanol production. In addition, it is assumed that the analyzed cellulosic plants will transport all of the biofuel produced via rail, thus, biomass delivery is the only significant effect on the road infrastructure. This section estimates the impacts of biomass transportation on road infrastructure for both scenario 1 and scenario 2.

Table 4.4: Fuelshed Size Comparison

	Scenario 1	Scenario 2	NREL Yield Estimate
County	(miles)		
White County	31	48	27
Tipton County	45	92	34
Marshall County	48	100	36
Average	41	80	32

Source: Author's Calculations (2009).

4.4.1 Vehicle Trip Miles (VTM), Truckloads and Length of Haul

The size of the fuelshed and the location of the biomass within the fuelshed directly translate into the impact that an individual cellulosic plant will have on the road infrastructure. Table 4.5 shows the impacts of the three most ideal plant locations in Indiana for both of the scenarios. Table 4.5 also shows the calculated infrastructure impacts using the NREL biomass to biofuel yield estimation. In order to estimate road impacts, one-way loaded vehicle trip miles (VTM), the number of truckloads required to deliver the biomass, and the average length of haul (LOH) for each plant were calculated under each scenario.

White County is projected to have the least total infrastructure impact, although it is still significant compared to the infrastructure impacts of grain-based ethanol plants. The total VTMs traveled for plant 1 are 1.3 million miles in scenario 1. It will take approximately 55,194 truck trips to deliver the necessary biomass for plant 1, thus establishing an LOH of 23.82 miles. The length of haul simply means that the average truck delivering biomass to the White County cellulosic plant will need to travel 24.1 miles from biomass origination to the physical plant location.

As more plants are built, the infrastructure impacts increase. The trucks delivering biomass to the Tipton County plant under scenario 1 will travel 1.7 million miles. This is approximately 27 percent more VTM than the impact of the White County plant. As the VTM increases, so does the average LOH which is estimated to be 30.6 miles for the Tipton County plant under scenario 1.

The third constructed cellulosic plant (Marshall County) is projected to have a total road impact of 1.9 million VTM. This is a 40.9 percent increase in road impact compared to the White County Plant. The LOH also increased from plant's 1 and 2 because it cannot source biomass that is contracted to go to the previously built cellulosic plants, thus increasing the distance required to source biomass to 33.7 miles.

Table 4.5 also shows the total road impacts for scenario 2. The estimated VTM for the White County plant is 2 million VTM, with the average length of haul increasing to 36.2 miles. The infrastructure impacts increase greatly for the subsequent plants under scenario 2. The Tipton County plant is estimated to cause 3.7 million additional VTM to the road network, an 88 percent increase over plant 1 in the second scenario. The Marshall County plant is projected to require 4.7 million VTM in order to deliver the biomass, and a LOH of 85.5 miles. The roads impacts for the Marshall County plant are 137 percent greater than the impacts of the White County plant under the same scenario.

Table 4.5: Infrastructure Impacts: VTM, Truckloads and LOH

	County	VTM (miles)	Truckloads (# trucks)	LOH (miles)
Scenario 1	White County	1,327,961	55,194	24
	Tipton County	1,686,617	55,084	31
	Marshall County	1,871,709	55,585	34
	Average	1,628,762	55,288	29
Scenario 2	White County	1,988,892	54,889	36
	Tipton County	3,748,019	55,037	68
	Marshall County	4,707,629	55,087	85
	Average	3,481,513	55,004	63
NREL Biofuel Conversion	White County	898,791	42,899	21
	Tipton County	1,024,560	42,122	24
	Marshall County	1,136,494	42,613	27
	Average	1,019,948	42,545	24

Source: Author's Calculations (2009).

The average impact in terms of VTM on Indiana's roadways for scenario 1 is 1.6 million miles per cellulosic plant, while the average VTM for scenario 2 is 3.5 million road miles per plant. Thus, a 51.7 percent decrease in the available biomass supply (scenario 1 farmer participation and removal rates verses scenario 2), is projected to increase the VTM by 114 percent. The reason for the large increase in VTM's relative to the reduction in biomass, is because of the competition effect of plants wanting to locate in the biomass rich areas of Indiana.

If the NREL estimations for biofuel yield become reality and cellulosic plants are able to collect biomass at the farmer participation and removal rates established in scenario 1, the total road impacts for a cellulosic industry in Indiana would be much less. Table 4.5 shows that average cellulosic plant would contribute approximately 1 million VTM assuming the NREL estimates, which is 37 percent less than the average VTM traveled under scenario 1, and 71 percent fewer VTM compared to scenario 2.

4.4.2 Vehicle Trip Miles (VTM) by Functional Road Class

To gain a better picture of the infrastructure impacts, the total VTM's established above were then broken-down by function road class (FC). The number of VTM per FC was estimated using the weighed FC percentage, as shown in section 3.4.3. In short, the weighted FC percentage determines the number of VTM's for each road class within a given buffer, taking into account the actual roads that are present and the preference of road travel based on the observation data. The summation of all road buffers within the fuelshed give the total VTM's per FC for each of the cellulosic plants. The total VTM's by FC are exactly equal to the total VTM's for the cellulosic plant.

The average VTM's per FC for a cellulosic plant in Indiana are shown in Table 4.6. In scenario 1, the largest portion of roadway travel, 46 percent, is projected to take place on 02 other principle arterial roads. Principle arterial roads are high capacity roads such as state routes or major county roads that flow traffic towards interstate highways. Both rural (FC 01) and urban (FC 11) interstates are each projected to see 12 percent of the truck miles delivering biomass to the cellulosic plants in scenario 1.

In scenario 2, rural interstates (FC 1) such as I-65 should experience 30 percent of the predicted VTM volume while urban interstate (FC 11) are predicted to have 24 percent of the VTM impact this road class. The increase in travel on FC 1 and FC 11 interstates is due to the increasing size of the fuelsheds for the cellulosic plants. As the fuelsheds increase, they intersect more miles of interstate highway, which are the preferable roads for truck travel. FC 2 is projected to have 807,260 miles of road travel for each cellulosic plant built under scenario 2, which is 23 percent of the average VTM's per plant.

Assuming the NREL biofuel conversion rate, 54 percent of truck traffic will occur on FC 2 roadways with only 8 percent of miles being traveled on rural interstates. Thus, this case suggests that the largest portion of infrastructure impacts stemming from cellulosic plants will take place on larger roads such as FC 1 and FC 2 roadways.

Table 4.6: VTM by Functional Class

	Scenario 1		Scenario 2		NREL Biofuel Conversion	
(FC)	VTM	% of Total	VTM	% of Total	VTM	% of Total
1	197,134	12%	1,057,280	30%	80,040	8%
2	745,022	46%	807,260	23%	547,840	54%
6	65,004	4%	89,335	3%	45,625	4%
7	50,726	3%	61,216	2%	36,995	4%
11	191,727	12%	827,677	24%	62,285	6%
12	220,619	14%	386,993	11%	142,743	14%
14	115,386	7%	187,742	5%	76,501	8%
16	43,145	3%	60,985	2%	27,920	3%
17	0	0%	3,026	0%	0	0%
Total	1,628,762	100%	3,481,513	100%	1,019,948	100%

Source: Author's Calculations (2009).

5. CONCLUSION

5.1 Overview

In order for a cellulosic biofuel industry to develop in states like Indiana, producers must believe that the plants will be profitable and that biomass collection is feasible. In addition, policy makers must be aware of all of the impacts of a future cellulosic biofuel industry, including the impact that biomass transportation will have on the road infrastructure.

An advantage that the cellulosic industry has compared to the grain based ethanol industry is that the development of cellulosic biofuel plants is likely to be much slower, allowing producers to be more strategic with regards to plant location. By minimizing the transportation distance required to source biomass, the cellulosic biofuel plants will improve plant profitability through lower marginal transportation costs and concurrently reduce the impact on road infrastructure.

The remainder of this chapter will review the key findings that a cellulosic industry will have road the infrastructure. In addition, study limitations and future research will be suggested.

5.2 Road Infrastructure Impacts

The formation of a cellulosic biofuel industry in Indiana will have major impacts on the road infrastructure surrounding each plant. This case study estimated the road impacts under two main scenarios, with the difference between the scenarios being farmer participation and removal rates. In addition, the study analyzes the effect of an increase in the biomass to biofuel yield on the road infrastructure while keeping the same farmer participation and removal rate assumptions as in scenario 1 (NREL Biomass Conversion).

The study finds that the average 50 million gallon per year cellulosic plant will need to have 55,146 truckloads of biomass delivered to the plant per year. This assumes that the biomass to biofuel conversion rate is 69.7 gallons per ton as in scenarios 1 and 2.

For this to be feasible, a truck will enter the cellulosic facility every 10 minutes; 24 hours a day, 365 days a year. If the biomass to biofuel yield of 89.7 gallons per ton occurs as predicted by NREL, then the average truckloads per 50 million gallon per year plant would decrease to 42,544. This would result in a truck being unloaded every 12 minutes.

The best indicator of road infrastructure impact is the VTM for each of the cellulosic plants. The case study finds that the VTM's are the smallest for the first plant built under all scenarios. Subsequent plants are forced to locate in areas of less biomass density; thus the LOH and the VTM's increase. The study finds by average scenario 1 and scenario 2 that there is a 64 percent increase in VTM's for 2nd plant built verses the first plant constructed. This increases to 98 percent more VTM for the 3rd built plant compared to the 1st built plant. The VTM increase for the NREL biofuel conversion estimate between plants is much less, which is attributed to less fuelshed overlap.

The road impacts of the cellulosic ethanol industry are substantial when compared to the road infrastructure impacts of the grain based ethanol industry. Table 5.1 shows the total VTMs for each of the scenarios in this study in addition to the total direct VTM impact of the grain based ethanol industry in Indiana. The total VTMs were divided by the total gallons of biofuel produced, thus allowing comparison between the smaller cellulosic facilities and the larger grain based ethanol facilities. Table 5.1 indicates that the VTM per gallon of biofuel produced is 318 percent higher in scenario 1 and 683 percent higher in scenario 2 when compared to the Indiana grain based ethanol industry (Quear, 2008). The NREL biofuel conversion estimate is projected to have a 201 percent greater VTM impact per gallon of capacity when compared to the grain based ethanol industry. It should be noted that scenario 1 is considered the 'best case' scenario for first generation cellulosic plants in this case study. Thus this study suggests that the infrastructure impact on a per gallon basis of cellulosic biofuel produced is sustainably higher than a gallon of grain based ethanol produced. In addition, the VTM's reported for the grain based industry as established by Quear, only include the VTM's impacted from direct incoming corn and outgoing DDGS. Quear suggested that the actual VTM impact for the grain based ethanol industry in Indiana is much less than reported below as shifts in lifestock consumption, crushing and exporting will change, thus lowering the total VTM caused by an increase in ethanol production (Quear, 2008).

Table 5.1: Cellulosic VTM Impacts Compared to Grain Ethanol

	Total VTM	Total Gallons Produced	VTM per Gallon	Grain Based
		(gal)	(vtm/gal)	% Change
Scenario 1	4,886,287	150,288,419	0.033	318%
Scenario 2	10,444,539	149,518,340	0.070	683%
NREL Biofuel	3,059,845	148,833,828	0.021	201%
Grain Based Ethanol *	4,656,100	455,000,000	0.010	100%

*Based on Quear, 2008 study. Only includes direct inbound corn and outbound DDGS impacts for 2008 scenario
Source: Author's Calculations (2009).

Trucks carrying biomass to cellulosic facilities will weigh significantly less than trucks transporting inbound grain and outbound DDGS from grain based ethanol facilities. In order to consider the weight differential, ton-miles per gallon of capacity were calculated for each scenario in Table 5.2. Ton-miles are simply the number of tons transported (trucks * load weight) multiplied by the number of miles traveled (VTM)[2]. The total ton-miles were then divided by the total gallons produced for each scenario to determine the ton-miles per gallon of capacity. Table 5.2 indicates that under scenario 1, the cellulosic ethanol industry will have a 202 percent greater impact on the road infrastructure compared to the grain ethanol industry on a ton-mile per gallon basis. The impact would be 402 percent more severe than the grain based industry under scenario 2. If the NREL estimates are accurate, then the cellulosic industry would have a very similar impact on the road infrastructure on a ton-mile per gallon of capacity basis when compared to the grain industry.

This case study finds that the functional road class usage varies for each cellulosic plant depending on the actual road classes available within the fuelshed. The results indicate that trucks prefer to travel on larger more well maintained roadways compared to smaller rural roads even though, more miles of smaller roadways exist within each of the fuelsheds. Table 5.3 indicates the average VTM usage by FC across the first two

[2] Tons transported for the cellulosic platforms are based on 14 ton empty tractor/trailer and 13 ton load capacity (Brechbill, 2008). Tons transported for the grain based platform are based on 14 ton empty tractor/trailer, 920 bu grain capacity (weighing 56 lbs/bu) and 25 tons capacity of DDGS (Quear, 2008)

scenarios. The results show that rural principle arterials (FC 2) will see 30 percent of the total cellulosic biofuel derived VTMs in Indiana. These are normally state routes and other major rural roads. FC 1, rural interstates, will be the second most impacted road class in Indiana with 25 percent of the VTM's occurring on this road type. It should be noted that the truck observation data lacked data for road classes 08, 09 or 19; thus, they were omitted from the VTM by FC calculations. It is highly likely that FC 08 represents the road class in which biomass originates as these are the rural minor collectors. Thus, the data in Table 5.3 should only serve as an indication of truck travel once the trucks reach FC 07 or larger roadways. Even if observation data existed for the small rural roads, the average daily count of trucks would be so low that the VTM by FC for FC 08 and FC 09 would be extremely small.

Table 5.2: Ton-Miles per Gallon of Biofuel Capacity

	Million-Ton-Miles	Total Gallons Produced	Ton-Miles per Gallon	Grain Based
	(in millions)	(saleable gal.)	(ton-mile/gal)	% Change
Scenario 1	21,882,270	150,288,419	145,602	202%
Scenario 2	46,534,108	149,518,340	311,227	432%
NREL Biofuel Conversion	10,544,573	148,833,828	70,848	98%
Grain Based Ethanol	32,816,272	455,000,000	72,124	100%

Source: Author's Calculations (2009).

5.3 Future Research

As more information surrounding the future cellulosic industry is available, assumptions in this study can be altered and the infrastructure impacts can be predicted more accurately.

The infrastructure impacts of the cellulosic biofuel industry could be expanded in several ways. Future research could vary plant locations based on a range of biomass availability assumptions such as farmer participation and removal rates. Currently the plant locations are assumed to remain fixed, even if the available biomass decreases due to lower than expected farmer participation or removal rates. The stationary limitation currently causes cellulosic plants to have substantial fuelshed overlap. Plant locations could also be varied based on the biomass to biofuel yield. The yield decreases the required tonnage of biomass, thus possibly changing the ideal plant locations in Indiana.

The case studies presented here provide information specific to the actual plant locations and other assumptions. However, the methods could be transferred to other locations to obtain the same kinds of road infrastructure impacts for other locations and assumption sets.

Table 5.3: Road Class Preference for Cellulosic Plant Locations

Road Class (FC)	Description	% of VTM's
2	Rural--Other Principle Arterial	30%
1	Rural--Interstate	25%
11	Urban--Interstate	20%
12	Urban--Other Freeway or Expressway	12%
14	Urban--Other Principal Arterial	6%
6	Rural--Minor Arterial	3%
7	Rural--Major Collector	2%
16	Urban--Minor Arterial	2%
17	Ubran--Collector	0%

Source: Author’s Calculations (2009).

LIST OF REFERENCES

Abbott, Philip C.; Hurt, Christopher and Tyner Wallace E. “What's Driving Food Prices?” Farm Foundation. 2008

Bain R.L. World Biofuel Assessment. World Biomass Potential: Technology Characterizations. National Renewable Energy Laboratory. NREL/MP-510-42467. December 2007

Brechbill, S. C and Tyner, W. E. “The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electrical Utility Facilities.” *Working Paper #08-03.* Purdue University, Department of Agricultural Economics. April 2008.

Federal Highway Administration. Vehicle Travel Information System. W-2 Table. Indiana 2009.

Indiana Department of Transportation. *FUNCTIONAL_CLASS_INDOTMODEL_IN: Functional Classification of Roadways (from INDOT Statewide Travel Demand MODEL version 4, ISTDM4) in Indiana (Indiana Department of Transportation, Line Shapefile).* 2004

Indiana Department of Transportation. “INDOT Functional Class (FC) Colors. 2007.9. Division of Planning.

Perkis, David, Wallace E. Tyner, and Paul Preckel. "Spatial Optimization and Economies of Scale for Cellulose to Ethanol Facilities in Indiana." Transition to a Bioeconomy: Risk, Infrastructure and Industry Evolution. Farm Foundation conference. Berkeley, CA. June 24-25, 2008.

Perlack, RD; Wright, LL: Turhollow, AF; Graham, RL; Stokes, BJ; Erbach, DC (2005, April). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-ton Annual Supply. US Department of Energy, US Department of Agriculture.

Quear, Justin L. “The Impacts of Biofuel Expansion on Transportation and Logistics in Indiana.” Purdue University, Department of Agriculture Economics. April 2008.

Renewable Fuels Association. *Industry Statistics.* May 2009.

Renewable Fuels Association. *Ethanol Biorefinery Locations.* 20 February 2008.

Sheehan J, Aden A, Paustian K, Killian K, Brenner J, Walsh M and Nelson R (2004). Energy and environmental aspects of using corn stover for fuel ethanol. *Journal of Industrial Ecology,* 7(3-4): 117-146

Tiffany, D. G. "Economic Comparison of Ethanol Production from Corn Stover and Grain." AURI Energy Users Conference. March 13, 2007.

Trimac Consulting Services LTD. "Truck Traffic Changes in Grain Transportation." Transport Canada Surface Policy and Programs. 1999

Tyner, W. E. "Ethanol Policy-Possibilities of the Future." *ID-342-W*. Purdue University, Department of Agricultural Economics. January 2007.

Tyner, W. E. "The US Ethanol and Biofuels Boom: Its Origins, Current Status, and Future Prospects." Bioscience. Vol. 58 No.7. 2008. Pp. 646-653.

U.S. Census Bureau. State and County QuickFacts.22 March 2009.

U.S. Congress (2007). *Energy Independence and Security Act of 2007*. H.R. 6, 110 Congress, 1st session. Available at http://www.whitehouse.gov/news/releases/2007/12/20071219-1.html.

U.S. Congress (2008). *2008 Farm Bill*. H. R. 6124 (P.L. 110–246).

U.S. Department of Transportation. Federal Highway Administration. VTRIS Table. https://apps.fhwa.dot.gov/VTRIS/default.aspx. 2009

Wright, M. M. and Brown R. C. "Comparative Economics of Biorefineries based on the Biochemical and Thermochemical Platforms." 17 May 2007.