A GEOGRAPHIC INFORMATION SYSTEMS APPROACH TO ESTIMATING DELIVERED COST OF ENERGY FEEDSTOCKS

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Abstract

Due to a large variation in the current research-based recommendations about economic or environmental cost-benefits, the ethanol industry's sustainable development may be adversely influenced. Moreover, one of the most important considerations for sustainable development of the ethanol industry – economics of transportation is often overlooked.

The primary objective of this paper is to explore economic feasibility of biofuels production in the state of Washington, and to report on the availability, collection and transportation costs of feedstocks for ethanol processing using Geographic Information Systems (GIS). The GIS Network Analyst Tool is used to spatially analyze forest residue biomass within given haul time area from the ethanol processing plant with the capacity of 55 million gallons per year (MGY). Using census feature classification codes, speed limits were assigned to road segments to calculate haul times to a biorefinery. Further, the farmgate price, transportation costs, biomass availability and geographic distribution information were integrated to derive feedstock supply curves.

Introduction

Despite the current industry progression, many questions regarding economic viability of alternative fuels processing such as ethanol still remain unresolved.

Despite numerous environmental benefits, a large portion of research efforts identify negative net energy balances with the corn-based ethanol due to fossil fuel energy usage for its production and distribution purposes (McCormick et al. 2003). One of the possible reasons for the disparity in research conclusions about economic or environmental cost-benefits of ethanol processing may be due to different modes of transportation efficiencies, and thus, different costs associated with them. Region- or site-specific road infrastructure and spatial features of data such as geographic distribution of feedstocks may significantly influence research recommendations.

The surging prices (USDA 2007) of corn used as feedstock for ethanol processing may force many ethanol producers out of business. One way to keep the “corn-in-control” is to process the ethanol from cellulosic materials that include corn stover, wheat straw, wood chip, switchgrass, poplar, etc. In addition to numerous environmental benefits, the main advantages of processing ethanol from cellulosic feedstocks are the resource abundance, higher energy returns (for several dedicated feedstocks, mostly switchgrass), and competitive production costs (McLaughlin et al. 2002). Another concern for many states is that given the scale of the growing ethanol industry, the acreage grown will not be sufficient for “locally supplied” corn-based ethanol processing.

However, besides current technological challenges of cellulosic feedstocks processing, there are other major issues to be investigated, such as the delivered cost of feedstocks, which may influence the delivered cost of the final product.

In an effort to explore economic feasibility of the ethanol production from cellulosic biomass in the state of Washington, the primary objective of this paper is to spatially investigate and report on the collection and transportation costs of forest residue feedstock using Geographic Information Systems (GIS).[1]

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[1] Forest residue includes residue both from forest thinning and logging.

Considering the geographic distribution of the forest residues in the state, the study area was chosen based on the location of the corn-based ethanol processing plant with the capacity of 55 MGY in Longview, Washington. The GIS Network Analyst tool is employed to investigate geographically varying forest biomass availability within different haul time zones from the ethanol processing plant. Using census feature classification codes, speed limits were assigned to all segments in the GIS roads shapefile to calculate feedstock haul times.[2] Assuming truck transportation, ten haul time categories with 30-minute (up to 5 hour haul time) intervals were used to estimate forest residue availability within each county and each haul time zone. Further, the procurement price, transportation costs, including loading and unloading, physical availability and geographic distribution (accounting for site-specific road infrastructure) information were combined to derive feedstock supply curves.

Literature Review

An estimation of the feedstock availability within a straight line radius around biorefineries by assuming average yields for the entire study area may generate misleading results. Factors that affect economics of biofuels processing, including landscape, proximity of feedstock collection area to a biorefinery may differ from one geographic region to another. Therefore, a more precise economic evaluation of biomass resources should take into account varying costs across hauling distance and local transportation infrastructure. Sometimes, depending on the situation, a more costly feedstock in close proximity may be cost-competitive compared to relatively cheaper biomass that is located farther away. Therefore, studies involving GIS allow evaluation of cost calculations over geographical areas and to model the spatial variation of transportation costs (using different haul times).

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[2] A shapefile refers to a file used in Geographic Information Systems that contains nontopological geometry and attribute information for the spatial features (roads in our case) in a data set. Feature information such as geometry and attributes (i.e., length of the segment, name, location, etc.) is stored as a shape containing a set of vector coordinates.

Longholtz et al. (2007) conducted a woody biomass feasibility study for 27 counties in the US southeastern states. Taking into account the spatial distribution and variability of the biomass resources, transportation costs were combined with the procurement and harvesting costs in order to derive the delivered cost. The methodology adopted by Longholtz et al. (2007), which was partially used in this paper with appropriate modifications, effectively reveals the spatial relationships pertaining to feedstock availability, which significantly increases the accuracy of the delivered feedstock cost calculations.

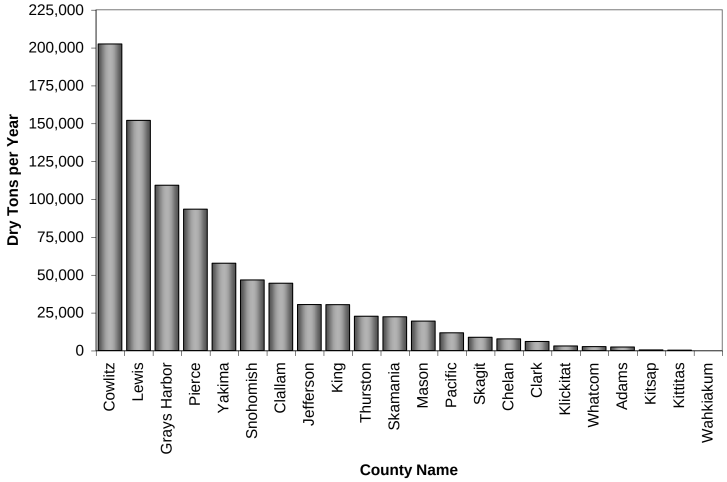
Among others, Graham et al. (1996), Noon et al. (1996), Möller and Nielsen (2007), Graham et al. (2000) and Zhan et al. (2005) developed a GIS based modeling systems to identify potential and optimal bioenergy feedstock locations. GIS can also be useful in determining most promising areas for biofuel processing plants in a given geographic region and the spatial distribution of biomass (Graham et al. (1995), Panichelli and Gnansounou (2007)).

Forest Residue Availability and Delivered Feedstock Cost Components

Washington State has abundant lignocellulosic biomass resources. The GIS data obtained from the National Renewable Energy Laboratory (NREL) identified urban wood, crops residue, primary mill, forest residue, methane emissions from landfill as the primary sources of biomass in the state. According to the biomass inventory assessment report by Frear et al. (2005), Washington's biomass is underutilized by 16.9 million annual tons. Based on the traditional 75 gallon per dry ton rate, NREL (2007) these data show that only forest residue category (10 percent of the state's total biomass) could support up to 77.5 MGY ethanol processing. Figure 1 provides annual availability of forest residue in the study area, which reveals underutilization equivalent to 65.5 MGY ethanol processing.

The cumulative availability of the forest residue in the study area is 873,507 dry tons annually, indicating the possibility to process up to 65.5 million gallons of ethanol annually. However, because of the spatial distribution of the biomass and the increasing transportation costs resulting from increasing distances, it doesn't mean that a processing plant with 65.5 MGY could be supported in some arbitrary location of the study area.

Figure 1: Forest Residue Availability in Washington State



The delivered cost of the feedstock highly depends on the distance hauled. A backward subtraction method will be useful in determining or putting a “cap” on the delivered cost of the feedstock. In other words, if processing and transportation costs are subtracted from the market price of the ready production, the “affordable” level of the delivered cost of feedstock can be determined.

Kerstetter and Lyons (2001) assessed county-level availability of logging and agricultural residue, and the economics of ethanol processing in the state. The study documented relatively higher recovery costs for logging residue, ranging from $30-80 per dry ton. Generally, residue recovery costs are influenced by the geographic characteristics such as slope of the land and accessibility of the residue collection area.

The collection part of the delivered cost of forest residue is a function of several considerations including resource availability, geographic location and landscape, equipment used and collection methods. The transportation component consists of loading, unloading, transportation to storage facility (if applicable) and to ethanol conversion facility. Given the geographic distribution of the forest residue, one would expect an increase in the marginal delivered cost, as the quantity demanded increases, since the hauling distances become longer.

Estimates of most recent studies including Gan and Smith (2006), Asikainen et al. (2002), USDA Forest Service (2005), Graham et al. (1997), Puttock (1995), provided the initial estimate for feedstock procurement prices, which in this paper is considered as $30 per dry ton. Trucking rates reported in Kerstetter and Lyons (2001) and Kumar et al. (2005) were adjusted according to current gasoline prices and used for the transportation cost calculations.

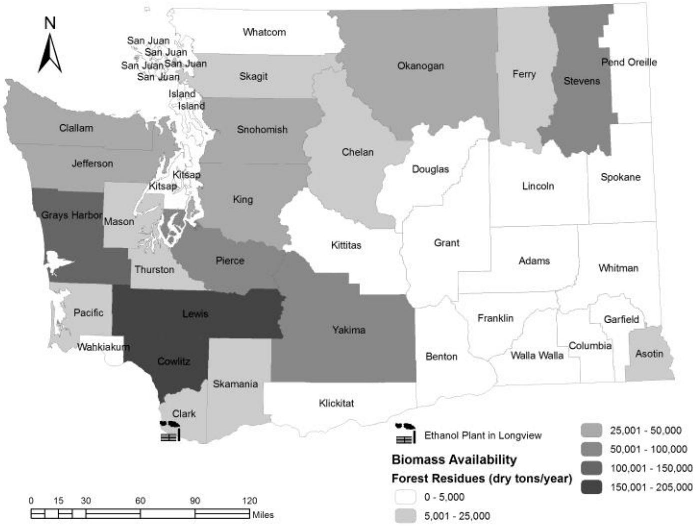
The GIS Approach and Procedures for Calculating Delivered Cost of Feedstocks

This section provides details on the GIS procedures for calculating resource availability by county and by haul times, defines the procedure of assigning speed limits and the process of generating datasets for the supply curves construction. Further, combined with the forest residue procurement price information, the supply curves are constructed and discussed.

GIS enables calculating transportation costs by incorporating spatial attributes of road infrastructure. Many research papers only consider linear, straight-line distances from the biorefinery neglecting local road infrastructure curvature and grade details. In order for the economic evaluation of biomass resources to be accurate, spatially varying availability, hauling distances, driving speed limits, trucking rates and collection cost information need to be integrated. Because transportation costs tend to increase with longer distances, in some situations it may economically be feasible to use relatively costly feedstock that is available within close distances from the plant, rather then hauling cheaper feedstock from longer destinations. Therefore, the use of the GIS allows investigating the delivered cost of a feedstock by integrating spatially varying distribution with the feedstock recovery costs and site-specific road infrastructure.

The Biomass shapefile represents a geographical layer where counties are depicted as polygons with attribute information, such as area, boundaries, population, etc., and spatial information, such as latitude, longitude and type of projection. The attribute table of the shapefile contains annual availability for crop, forest, primary mill, secondary mill, urban wood residues and switchgrass (in dry tons), and methane emissions from manure management and domestic wastewater treatment (in tons) per county. As indicated earlier, the forest residue category was selected for the analyses in this paper. Figure 2 provides county-level forest residue mapping using the GIS data.

Figure 2: Distribution of Forest Residue in Washington State

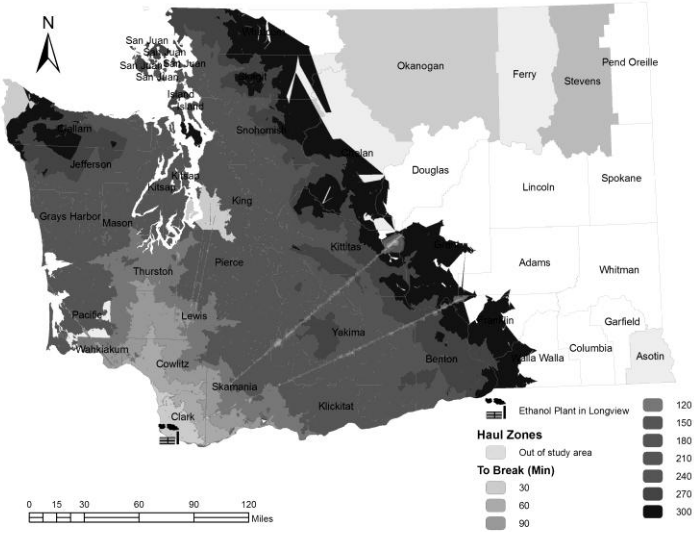


U.S. Census Topologically Integrated Geographic Encoding and Referencing (TIGER) road shapefiles for the study area counties were obtained through the Environmental Systems Research Institute (ESRI) website. Census feature classification codes (CFCC) were joined to the roads shapefile attributes table to assign speed limits to each of the road segments. Further, the feet measure of line features was converted into miles, which allowed calculating travel times for each road segment using the following formula:

$$\text{Travel time} = \text{road segment length} \times (60/\text{speed limit})\,.$$

Using GIS Network Analyst extension the road shapefile was converted into a network dataset. The Network Analyst extension enables network based spatial analysis, such as finding the closest facility from a particular location, identifying routes, identifying driving directions and mapping service areas based on distance (miles) and/or travel time (minutes) from/to specific locations. Using Network Analysis toolset the service area layers as then mapped and illustrated (shown in Figure 3).

Figure 3: Forest Residue Availability by Haul Times



As mentioned earlier, the spatial investigation considers the actual geographic location of the ethanol processing plant with the capacity of 55 MGY located in Clark County (southwest). Note that in order to keep the map simple, the road layer is not displayed.

Hereafter, haul zone is used to refer to the service area mapped by service area GIS Network Analyst function as shown in Figure 3. Haul zones were calculated with 30-minute intervals (up to 300 minutes) from the origin (plant location) using travel time as the primary cost attribute. For example, in the 30-minute interval zone, all biomass can be transported from the field to the plant within 30 minutes of drive time. The next haul zone is mapped as 30 – 60 minutes haul zone, meaning the amount of feedstock available in that zone takes from 30 to 60 minutes of drive time for transporting to the plant.

The term haul area differs from the haul zone by including inner zones. For example, 60-minute haul area includes feedstock available from both 0 – 30 and 30 – 60 minutes haul zones. The reason to conduct the analysis based on travel time rather than on the distance attribute involves varying site-specific road infrastructure and geographical constraints, including varying elevation (Longholtz et al. 2007).

The haul zones are then saved as a separate layer (shapefile) and stacked together with the biomass layer such that for each haul zone the feedstock amount in tons is available. Since the biomass data is assigned per county, it is not possible to simply "cookie cut" the biomass layer with the haul zones. First, the haul zone layer is merged with the biomass layer. Then, the areas within the boundaries of each haul zones are selected from the merged layer and saved as another layer. In this selected layer the area (square miles) for each of these haul zones in each county is calculated using ArcMap geometry calculation tool. Finally, the attribute table was exported into the spreadsheet format to plot charts.

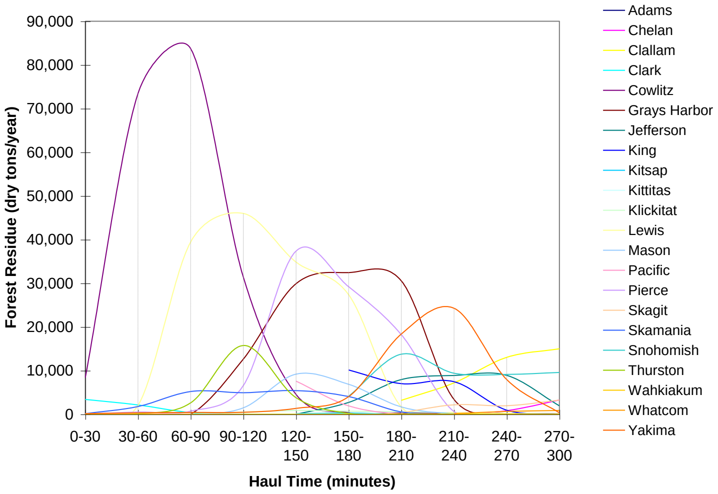
The proportion of each haul zone in each county can be calculated by dividing the area of the haul zone (within the boundaries of that county) by the area of the county itself. Certainly, the spatial manipulation of the data is enabled by the GIS and would be very challenging using only spreadsheet analysis.

Results

The attribute table of the selected layer comprised of feedstock and haul zones information was concatenated and exported into spreadsheet such that it allows identifying the amount of feedstock available in each haul zone and each haul area in each county. In order to construct resource availability curves using haul zone proportions, a key assumption is required – a homogenous distribution of the biomass within the boundaries of each county.

The amount of feedstock availability in each haul zone is depicted in Figure 4. The cumulative availability across each haul zone area is provided in Figure 5. Depending on the specific objective, both methods of expressing feedstock availability can be useful. Figure 4 is more useful when information on resource availability within the next haul time category is needed.

Figure 4: Forest Residue Biomass Availability by Haul Times



In other words, given the geographic distribution of feedstock, by driving one more hour (to reach more distant areas), the figure provides information about the resource availability specifically in each additional haul zone. If accrued expenses from driving one more haul category is considered, the figure can provide information relative to whether the marginal value was "worth it."

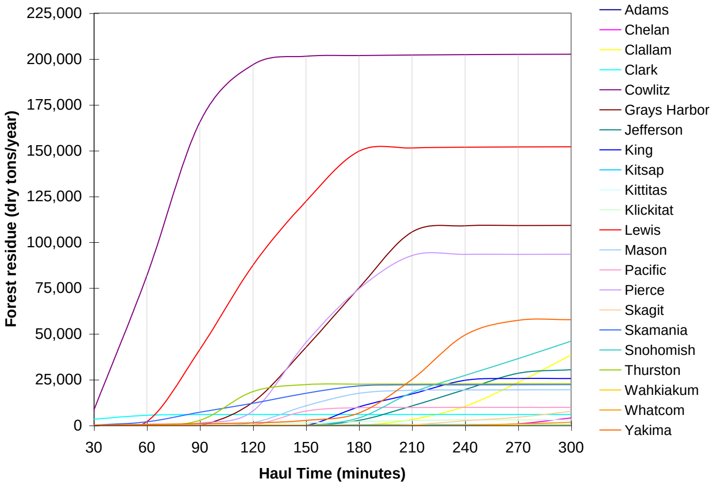
As shown in Figure 4, the biomass availability reaches the highest levels of availability at 60 – 90 minutes zone for Cowlitz County, 90-120 minutes zone for Lewis. Similarly, 120-150 minutes zone for Pierce, 180-210 for Grays Harbor and 210-240 for Yakima Counties.

On the other hand, if the plant operations management is interested in knowing the total supply of the feedstock within certain haul times, the Figure 5 will be more appropriate, since it shows cumulative availability of feedstocks. For instance, resource availability in counties Grays Harbor and Pierce reach maximum cumulative availability at around 210 minutes of haul time. Counties

Cowlitz and Lewis can provide maximum resource availability at around 120 and 180 minutes of drive time respectively.

The derivation of feedstock supply curves involves several components. The processing capacity that available feedstock can support was found using conventional 75 gallons per dry ton rate.

Figure 5: Cumulative Forest Residue Biomass Availability by Haul Times

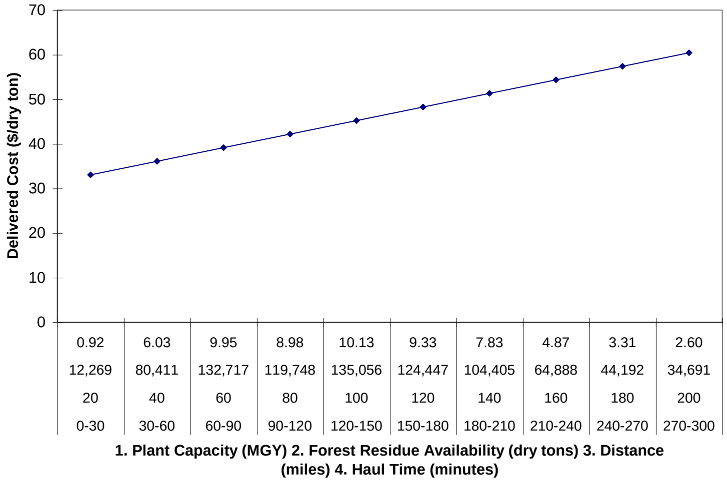


Another important measure is the resource availability within various haul time zones. Haul times used for the supply curve construction were adjusted for transportation delays, such as stops, turns, and slow speed road segments. Figure 6 illustrates the relationship between the delivered cost of feedstock per dry ton (for the ethanol processing plant depicted in Figure 3) and the quantity, as well as plant capacity, distance and haul times.

Notice that similar to haul zone and haul area concepts, the quantities in Figure 6 are again expressed for specific (from – to) haul zones. On the horizontal axis, the first measure shows an incremental plant capacity that the feedstock available in a given haul zone (separately) can support. The second line represents the amount of forest residue available within the boundaries of specific haul zone. The distance measure is included in order to complement the haul times.

For example, in Figures 6, consider that the plant proposes to increase its annual ethanol processing above 53.17 MGY (i.e. summed capacity up to 180-210 haul zone). Then, by increasing the haul time by 30 minutes, an additional 4.87 MGY equivalent feedstock will be available. Haul time based calculations matter more than the distance, since for the same-length hauls there can be different road infrastructure or geographical constraints.

Figure 6: Feedstock Supply Curve by Haul Zones



By applying the same trucking rate on the distance basis, site-specific road infrastructure will be ignored, thus producing misleading costs.

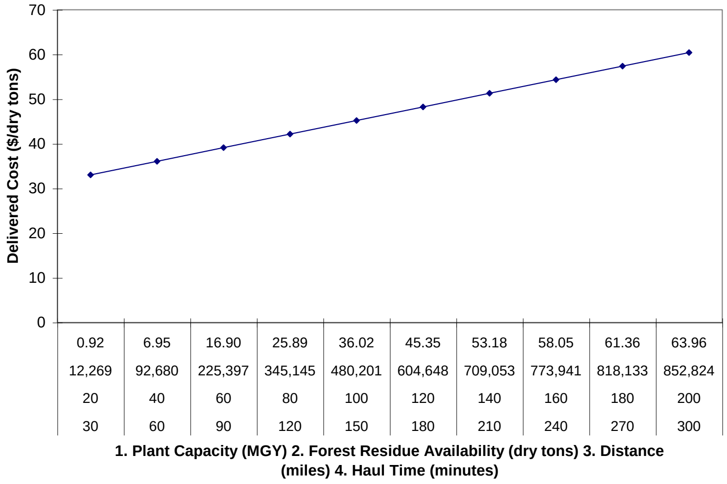
The cumulative feedstock supply curves can be more informative to determine the capacity that an ethanol plant could “afford” to process. Figure 7 shows the relationship between the delivered cost of feedstock per dry ton and cumulative quantity, as well as cumulative plant capacity and haul times. Since the farmgate price is the same throughout the study area, this relationship emphasizes the importance of the transportation component in determining the delivered cost of feedstock.

Depending on the plant capacity (i.e. quantity demanded), the delivered cost of feedstock can be determined. Particularly, for the real geographic location of the 55 MGY plant that was mapped in

Figure 3, the delivered cost was found $52.82 per dry ton. More feedstock, and thus, higher processing capacity (up to 63.96 MGY) could be supported within the area under investigation by increasing haul distances (with the consideration of increasing delivered costs).

As promised earlier, supply curves constructed using GIS-generated data help in assessing the "optimal" size of the plant given not only the availability of the feedstock in the study area, but also the geographic distribution and local road infrastructure.

Figure 7: Feedstock Supply Curve (Cumulative)



In order to assess the benefits from the economies of scale, processing costs need to be investigated as well.

Conclusions

Feedstock supply curves suggest that processing plant capacity and the geographic distribution of feedstocks may significantly influence the delivered cost of feedstock. Thus, the large capacity plants are not necessarily advantageous from economies of scale as it pertains to the feedstock production, because more capacity requires longer feedstock haul destinations. Due to the spatially variable forest residue availability, the total biomass that is available in the region cannot be fully utilized at the same expense.

Therefore, as a part of the interrelated structure of ethanol processing and distribution, transportation costs prove to be a key component for the feasible feedstock supply system.

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