Assessing Agricultural Biomass Using Geographic Information Systems

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Abstract

There is a growing demand for energy and that demand is primarily supplied by fossil fuels. These fuels have a limited availability, as they take thousands of years to create. Biomass offers a potential source for renewable and sustainable energy. Stevens County, Minnesota, may be an optimal location to develop agricultural biomass resources, as much of the land is already dedicated to farming. This paper looks at crop residues and energy crops that can be used as biomass and discusses some of the variables that must be considered to analyze the potential of energy crop utilization.

Geographic Information Systems (GIS) are becoming a critical technological resource. This computer-based software can be used for spatial analysis and to create graphical representations, allowing users to accumulate and share accurate and precise data. Geographic Information Systems can be used to analyze soil types, slopes, elevation, ground water, flood zones, weather patterns, use satellite images to represent vegetation health, map transportation routes, storage space, plot CRP lands, and find optimal locations for biomass energy conversion plants. This research reviews how GIS applies these analyses at a county level with examples from Stevens County, MN.
Introduction

As technologies advance and populations grow, there is a rising demand for energy. Not only is more energy needed, but the means by which energy is supplied should be sustainable. This is to say that this generation must seek to meet current energy needs without limiting the ability of future generations to do the same. One component of sustainable energy is acquiring renewable sources. Biomass offers considerable potential as a renewable energy source. Biomass is any renewable organic material including: agricultural crops and residues, grasses, trees, wood waste, animal wastes, etc. (US EPA, 2007a).

Having land previously adapted to agricultural growth can simplify developing biomass as a renewable energy source. This assumes that the land and soils have been and will continue to be productive. Agricultural biomass can be produced from crop residues or energy crops with the possibility of using lands registered in the Conservation Reserve Program (CRP) in addition to currently in production. With the growing demands for sustainable energy, it is imperative to use advancing technologies to assist in the assessment of biomass production viability and efficiency.

A Geographic Information System (GIS) is a computer-based technology allowing users to analyze and visualize nearly any spatially-referenced data. Spatially-referenced means associating characteristics (e.g. name, color, shape, soil type, amount of rainfall, etc.) with a place, whether geographic (e.g. latitude/longitude) or relative to something else (e.g. the storage unit is 5 miles south of the energy facility). Geographic Information Systems can be used to work with aerial photographs, satellite images, Digital Elevation Models (DEMs), and digitizing maps. Instead of the original survey
method (using measuring tapes, pens, and paper), some people are expanding to use technologies such as a Global Positioning System (GPS) for mapping. A GPS is a computer-based tool that pinpoints the user’s location, often capable of storing these points and traveled paths. Transportation distances can be mapped and travel times can be calculated by combining desired routes with what road types are used (which determine an estimated speed limit). This example may be taken for granted as many people use this feature commonly found on websites such as MapQuest, Google Maps, Yahoo! Maps, etc.

For the purposes of assessing potentially available biomass, GIS can be a very important tool for locating and planning the transportation and storage of the biomass. The first step is finding possible locations for the development of biomass. Here, GIS can be used to assess current land use, elevation, slope, soil types, weather patterns, water flow, etc. All of these can be combined to assess the possible productivity of using the land for biomass production. It is also necessary to consider the distance the biomass must be transported to be stored and used. This information will be used for the assessment of economic costs and benefits to both the buyers and sellers. Geographic Information Systems may also be beneficial in determining a location to build an energy conversion facility by looking at land use and transportation costs. After the energy facility has been constructed and is operational, there are still important aspects to consider, such as pollution or emergency operations. Geographic Information Systems can be used to look at what or who might be affected by possible emissions, how pollutants could move throughout groundwater, etc. Along the same lines, GIS can help prepare an emergency escape plan by taking into account who and how many might be
affected by certain emergency situations, possible escape routes, how long it might take for emergency vehicles to reach the facility, etc.

For the purposes of this research, GIS will be used at a county-level scale, more specifically looking at Stevens County, Minnesota to demonstrate its use in assessing potentially available agricultural biomass.

**Soil**

Maintaining soil health is crucial in developing productive crops. Soil health is complicated to measure as it encompasses many physical, chemical, and biological factors. These soil properties reflect productivity levels as they show: respiration, pH levels, available plant nutrients, possible nutrients to be lost, areas more prone to erosion, the capacity to retain and move water, etc. (Acton and Gregorich, 2006; USDA). Some critical components classifying soil health can be measured (e.g. pH and nitrogen levels), while others are more observable (e.g. erodibility).

One concern regarding decreasing soil health is erodibility. Soil erosion is the phenomenon of wind and/or water removing topsoil. Erosion is a natural process that can be amplified by agricultural use, but is damaging to the sustainability of crop lands. Agricultural lands in the United States can lose several tons of soil per acre per year, though conservation incentive programs have helped these rates decrease. Stevens County, Minnesota is located within the Souris-Red-Rainy/Upper-Mississippi river basin where soil erosion of croplands has decreased from 7.6 tons per acre per year in 1982 to 5.1 tons per acre per year in 2003 (USDA NRCS, 2007). An important part of these
incentive programs is educating people about what erosion is and how it happens (US EPA, 2007b).

Wind erosion is the process by which wind removes some of the topsoil. This process can be thwarted by leaving agricultural residues on the croplands and planting trees or shrubs to create a windbreak. Water erosion is caused by the force of raindrops falling on the soil or, more severely, by overland water flow. This can be reduced by leaving agricultural residues, planting cover crops, planting grass waterways, and building terraces to guide overflow (US EPA, 2007b). Some soils are more prone to erosion than others. The soils most vulnerable to erosion are those with a lower density, such as clays and silts. Unfortunately, these same soils tend to be the most fertile, leaving a noticeable negative impact on the agricultural development (US EPA, 2007b).

Geographic Information Systems (GIS) are useful for monitoring the various components of soil health. The Minnesota Department of Natural Resources Data Deli (MN DNR, 2008) and the United States Department of Agriculture Natural Resources Conservation Service Soil Data Mart (USDA NCRS, 2008) provide free downloadable files of soil surveys. These data can be used as a reference for locating different soil types and properties. Figure 1 is an example of the data provided from the MN DNR. This map shows a simplified reference of the five major soil groups in Stevens County, MN according to Cummins & Grigal, 1980. These groupings show characteristics of texture and the ability to hold nutrients and water. Figure 1 shows that Calciaquoll, for example, is one of the major soil groups in Stevens County, MN. The Cummins & Grigal report shows that Calciaquoll has the characteristics of containing medium to high amounts of nutrients with the permeability primarily affected by the texture. Though the
soil texture, nutrients, and permeability can help indicate overall soil health, these are not the only determining factors. The terrain can also affect water flow, the amount of available sunlight and nutrients, and erodibility.

**Terrain Analysis**

Most terrain analyses are constructed from a National Elevation Dataset (NED) (e.g. Figure 2). These NED are high-resolution, seamless, raster data of the United States (USGS, 2006). Using Geographic Information Systems (GIS) software, NEDs can be used to calculate contour lines, hillshade, slope, and aspect.

Contour lines represent the locations of specific elevations and are often placed on maps to help visualize slopes. Figure 3 shows contour lines representing 10 meter elevation intervals in Stevens County as an example. A hillshade model depicts what would happen if an infinite light source was shown down upon a particular area. This is done through the calculations of the local horizon and elevation. A hillshade can then show what is illuminated and, in some cases, also show the shadows created by the terrain (ESRI, 2008). Figure 4 demonstrates this in Stevens County, MN.

Slope and aspect are also valuable when studying the terrain. Slope is the rise over run and is expressed in degrees or as a percent. Figure 5 shows the slopes in Stevens County, Minnesota represented as percents. Aspect reflects the steepest downhill direction at a given point. The values are represented as azimuth angles (between 0 and 360), with zero representing North and increasing clockwise (Bolstad, 2006). This is demonstrated in Figure 6, an aspect model of Stevens County, MN.
All of these properties are used to assess quality terrain for vegetation. Elevation can reflect the temperature and what type of vegetation might thrive in that location. Slope affects water flow, erosion, the ability to develop infrastructures, and the ability to harvest. Aspect defines the path of water flow, the amount of sunlight received, and the possible success of vegetative growth. Combining all of these properties is useful for planning crop types and the location for harvest (Bolstad, 2006).

Though hardcopy paper maps have traditionally been the only way to document terrain properties, they are very time consuming to produce and prone to error. With developing technologies, GIS has become the most efficient way to document these properties while allowing for accurate, consistent, and easily transferable data (Bolstad, 2006). Geographic Information Systems allow users to easily visualize the data and manipulate it for different types of analyses.

With available spatial analysis tools, GIS provides the ability to combine elevation, hillshade, slope, aspect, etc. to pinpoint optimal biomass harvesting locations. Each property can be represented as a single layer of a map. Each layer is then simplified into what is favorable versus what is not, using a true-false method. By declaring the values necessary for harvesting, GIS allows the user to state what values fall into a suitable range (those that are suitable would be ‘true’ and the others would be ‘false.’) This separation can be clearly visualized using a single color for ‘true’ and another for ‘false.’ For example, the optimal slope for the growth of a particular crop might be a slope of less than 20 degrees. A software tool is then used to identify all the areas with a slope less than 20 degrees and visually distinguish those locations with the color green, leaving the rest black.
Since harvestable lands are not simply classified with one variable, it is necessary to analyze multiple layers of data. The same true-false method can be used to analyze multiple layers. A user would overlap all the data, identify all of the necessary variables, use the same GIS software tool to identify the locations containing those variables, and then associate those locations with a color. Figure 7 shows specified hillshade, slope, and aspect values as a hypothetical example of how these features could be used to find an optimal harvesting location. The areas sharing all of the specified features simultaneously are displayed in blue and those that do not meet all of these requirements are displayed in gray. If the values used in this example were the preferred features for producing a particular species, the locations represented in blue would be optimal.

Transportation

The efficiency of shipping the feedstock from the site of harvest to the site of energy conversion is also important, as sustainability does not just account for the practices of developing biomass and how resourcefully the feedstock is converted into energy. As the cost of fuel increases, the cost of shipment will also increase. Due to the rising costs of fuel, the further the feedstock must be transported, the more likely it becomes for the process to lose profitability. Not only could long distance transportation be economically costly, but the emissions from transportation vehicles at long distances might counter some principals of sustainability, a major reason for developing a biomass energy facility in the first place. To keep the environmental and economic impacts of transportation to a minimum, there have been various assessments seeking an optimal range of how far away biomass should be grown from where it will be converted into
energy. The optimal range is going to vary depending on the type of feedstock used, the type and size of the industry providing the feedstock, and the type of contracts made between the provider and buyer.

The type of feedstock is important to consider because the deterioration rate will determine the time frame available to get from the farm to the biomass plant. The density of the product will determine the size of loads and how many trips will be necessary to provide enough energy to the plant. The farming industries providing the feedstock could be small local farms or they could potentially be very large. With larger projects, there may some allotted bulk discount, which could improve the profitability of shipping from further away. The type of contract will have an impact in that the directors of the energy facility might have farms to manage on their own and have consider each variable in the production, gathering, and transportation to get the feedstock to the plant. If contracting outside, the producers might consider all of those costs and the directors would just have to look at the total estimated prices from possible contractors.

When researching transportation costs, there are Geographic Information Systems available to help plan the travel costs. With GIS software, such as ArcGIS, it is possible to look at and display an optimal transportation zone. One can find, download, and import files (e.g. shapefiles) from an online data source showing cities (and/or other types of political boundaries.) With this data and GIS software, a certain point can be chosen (such as an agricultural location or a biomass plant). Once this point is chosen, there is a tool to create a buffer zone around the selected feature. This buffer zone is a shaded visualization of the space surrounding the selected feature. This buffer zone can be made any size, allowing the visualization of what cities, agricultural sources, biomass plants,
etc. might fall within the desired range. For example, Figure 8 shows a 10 mile buffer zone around the approximate location of the biomass gasification plant in Morris, MN.

There are also various GIS tools publicly available online that can help assess transportation distances. Many popular search engines provide these online mapping services: MapQuest, Google Maps, Yahoo! Maps, and MSN Live Search Maps are just a few examples. These mapping tools allow users to plug in the name of a city, place, address, etc. and the program will display a map of that area. Many of these services, creating maps on demand, have now upgraded to include the choice of viewing these locations through satellite images. These programs not only show a map of the location, but will also provide driving directions to any continental destination, followed by an estimated time of travel. To do this, the program marks each location and then, using the most updated documentation of available roads, will find the shortest path. When the roads are recorded, they include a specific road type, which reflects the speed limit. With the distance of the roads and the speed limit, the program calculates an estimated travel time.

These online mapping programs also allow the choice of a preferred route based on either shortest travel time or shortest distance. This helps expand the transportation options, leaving room for more economic cost-benefit analysis. Most of the online mapping programs will automatically choose the quickest route. This might actually be a longer path containing roads with higher speed limits. These programs will allow users to choose the route with the shortest distance, which could take more time but be more fuel efficient. These programs can help contractors plan the transportation costs-analysis
when deciding whether it is more beneficial to pay the drivers for shorter trips and more fuel or vice versa.

Storage

The amount of storage space available and needed for the feedstock must be considered when assessing the costs and feasibility of using biomass for energy. To determine the available storage space, some Global Position Systems (GPS) can be used to digitally survey the area.

A GPS works by communicating with satellites, receiving radio waves transmitted by the satellites to determine the location of the user. A minimum of 3 satellites is required to calculate the location of the GPS; with more satellite signals the GPS reading will be more precise. (Bolstad, 2006). Global Positioning Systems have the ability to capture location points, storing them in their memory. Combining the satellite signals with the GPS computer and memory, users are able to track their movements. The GPS is then able to use mathematical calculations, based on the satellite signals and projections of the earth’s surface, to estimate the distances associated with these tracks. To calculate an area, the GPS unit is walked the desired area to create a closed track. Using the distances between points around the perimeter, the GPS will determine the area. It is important to note the quality and precision of the tool, as not all simple GPS models are qualified for surveying.

A Trimble GPS unit was used to survey the storage space currently available for the feedstock that is stored for the biomass gasification plant in Morris, MN. At the time of this survey there were two field lots (North and South) holding bales of corn stover
and piles of wood chips. Each of the lots was tracked individually, followed by the measurements of each set of bales or wood chips. With that information, it was possible to see how much space is available and how much space will be needed for the feedstock.

The results for the spatial assessment are displayed in Table 1. According to the data, approximately one-fourth of the total storage space in the South lot is currently occupied. To assess how much biomass could be stored, refer to Table 2. This shows how much space was used by each row of bales. The space used for each bale can then be calculated, but it is important to consider what type of bales (round or square), how dense (e.g. 800lb bales), and how they are stacked. For the corn stover in the South lot, the bales are round, about 1,000 lb., and they are stacked 3-2-1 (3 bales across the base, then 2 bales stacked on top of the previous, and 1 more on top of that, giving the cross-section a triangular shape). Each bale takes up an average of 2.14 square meters of ground space. A user could then estimate how much feedstock from this particular provider can be stored in the space remaining.

Even though the amount of unoccupied space available is now known, there are still some points to consider before declaring the amount of usable space. Though they can be quite close, the rows/piles of feedstock cannot be stored completely against each other and this space must be accounted for. Depending on the type of feedstock, space, and delivery vehicles, there may be dugouts or turnabouts established within the lot. This is the case for the South storage lot in Morris (Figure 8), where there is a dugout for loading the wood chips. There might also be roads, paths, or obstacles reducing the available space. An indoor storage facility may not have this problem, but open fields might not always have optimal terrain to properly store feedstock. If the ground has steep
slopes, heavy vegetative growth, or uneven ground the feedstock, such as stacked bales, could be more apt to falling and breaking. Using this sort of terrain without clearing or leveling may result in the loss of feedstock. In this case the land could be leveled or filled in before use as storage space, but the machines and labor for this process is another cost to be considered.

Geographic Information Systems can be of assistance when analyzing these circumstances, allowing users to create visual representations of their possible storage space. The points and tracks taken with a GPS can be transferred to a computer and, with GIS software, graphically visualized. The ability to visualize this data is important in addressing the previously mentioned concerns. Instead of having paper maps, the information can be digitized, which allows users to conveniently alter the data, store the documents, and share the findings with others.

This process was used for both of the storage plots in Morris, MN (Figure 8 and 9). For the purposes of visualization and reference, a Digital Orthophoto Quadrangle (DOQ) was downloaded and used as a base map for the GPS tracks. A DOQ is a computer-based image made of aerial photographs that have been adjusted to compensate for terrain and camera tilt (USGS, 2001). The result is an image that geometrically looks like a map and becomes very useful for GIS. They can be found publicly and downloaded for free; the DOQ used for the storage assessment in Morris, MN was downloaded from the MN Data Deli website. This site is provided by the Department of Natural Resources (DNR) and receives data from the United States Geological Survey (USGS).
Other Uses for GIS in Assessing Available Biomass

Geographic Information Systems are currently used to display weather patterns and climate. Some of these features may include the amount of rainfall, how many months of rain is received, average temp, and how these may be shifting. This directly impacts the success rates of crops, as each species will have a desired range of necessary water and temperature. There are also GIS programs specially focused to work with water movement. These programs can help assess bodies of water, underground water sources, permeability, water pathways and speeds. These factors help determine the viability of harvesting locations because of water supply and erodibility.

Geographic Information Systems can also be useful once the biomass has arrived at the energy facility. One very useful way GIS can be used is to monitor pollution from the facility. Depending on what type of facility, what type of conversion process, what type of biomass, and where it is located there are going to be possibilities of pollution. There might be routine daily emissions moving through air or water. Looking at weather patterns or water movement combined with the location can help determine possible damages or effects. This can also be used to predict damages of a larger pollution or emergency accident. This will be important in creating an emergency clean-up and response plan.

Conclusion

The accuracy, consistency, and transferability make GIS a time saving technology. Along with saving time, GIS saves money by preventing mistakes and creating a universal system for data collection and compilation. The conveniences of
these programs allow many users, from the average person to a specialized technician, to create and share data and visualizations. With just a few examples, it is evident that GIS can be applied to the processes of locating and gathering biomass, such as in finding possible harvestable locations, transporting the feedstock, and storing the biomass.

Geographic Information Systems are beginning to be used during the actual agricultural harvesting itself. Mobile GIS programs, with the assistance of GPS, are allowing users to plan harvesting locations according to the history and health of the soils ("Harvesting efficiently using mobile GIS," 2008.) These technologies are also used on the harvested lands to help plant more precisely and beneficially. These features are merging together in hopes to correlate all of the pieces and processes together. It would be convenient to mark harvesting sites in accordance to the soil health, define the harvested materials, mark where those exact materials are going, how far they travel, how long it takes from harvest to the energy conversion, and even to how much energy is produced. This would be optimal for improving the efficiency of crop development and use. New technologies can be very useful in this way and it is important to be educated in these ways. Geographic Information Systems is a technology constantly advancing, allowing for the opportunities to assist and improve along all the steps of assessing and using agricultural biomass.
Table 1. Space in the South storage lot in Morris, MN.

<table>
<thead>
<tr>
<th>Item</th>
<th>Area (m²)</th>
<th>Area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire Lot</td>
<td>8,716.00</td>
<td>2.15</td>
</tr>
<tr>
<td>Corn Bale Row 1</td>
<td>212.71</td>
<td>0.05</td>
</tr>
<tr>
<td>Corn Bale Row 2</td>
<td>216.68</td>
<td>0.05</td>
</tr>
<tr>
<td>Corn Bale Row 3</td>
<td>226.94</td>
<td>0.06</td>
</tr>
<tr>
<td>Corn Bale Row 4</td>
<td>248.47</td>
<td>0.06</td>
</tr>
<tr>
<td>Corn Bale Row 5</td>
<td>202.82</td>
<td>0.05</td>
</tr>
<tr>
<td>Corn Bale Row 6</td>
<td>223.68</td>
<td>0.06</td>
</tr>
<tr>
<td>Wood Chips 1</td>
<td>449.51</td>
<td>0.11</td>
</tr>
<tr>
<td>Wood Chips 2</td>
<td>332.52</td>
<td>0.08</td>
</tr>
<tr>
<td>Truck Dugout</td>
<td>123.11</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Total Occupied Space</strong></td>
<td><strong>2,236.44</strong></td>
<td><strong>0.55</strong></td>
</tr>
<tr>
<td><strong>Remaining Unoccupied Space</strong></td>
<td><strong>6,479.56</strong></td>
<td><strong>1.60</strong></td>
</tr>
</tbody>
</table>

Table 2. Average area per bale stacked in rows of 3-2-1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Area (m²)</th>
<th># of Bales in Row</th>
<th>Area (m²) per Bale</th>
<th>Area (ft²) per Bale</th>
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</thead>
<tbody>
<tr>
<td>Corn Bale Row 1</td>
<td>212.71</td>
<td>103</td>
<td>2.07</td>
<td>22.23</td>
</tr>
<tr>
<td>Corn Bale Row 2</td>
<td>216.68</td>
<td>96</td>
<td>2.26</td>
<td>24.30</td>
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<tr>
<td>Corn Bale Row 3</td>
<td>226.94</td>
<td>108</td>
<td>2.10</td>
<td>22.62</td>
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<tr>
<td>Corn Bale Row 4</td>
<td>248.47</td>
<td>108</td>
<td>2.30</td>
<td>24.76</td>
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<tr>
<td>Corn Bale Row 5</td>
<td>202.82</td>
<td>101</td>
<td>2.01</td>
<td>21.62</td>
</tr>
<tr>
<td>Corn Bale Row 6</td>
<td>223.68</td>
<td>107</td>
<td>2.09</td>
<td>22.50</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>221.88</strong></td>
<td><strong>103.83</strong></td>
<td><strong>2.14</strong></td>
<td><strong>23.00</strong></td>
</tr>
</tbody>
</table>
Soil Great Groups of Stevens County, MN

This map displays the soils and land surfaces of Stevens County, Minnesota derived from Cummins and Grigal, 1980. They combined five elements: parent material, climate, relief, organisms, and the amount of time the first four elements have interacted, to help interpret possible uses for the land.

Datum & Projection: NAD 83 UTM Zone 16N
Data Source: MN DNR Data Deli
Map Created: On 04 August 2008 by Brittany Crocker
Figure 2.

National Elevation Dataset of Stevens County, MN

This map displays a National Elevation Dataset with the property lines of Stevens County, MN. Within the county are the city municipalities.

Data Source: USGS and MN DNR Data Deli
Map Created: 11 August 2008 by Brittany Crocker
Elevation Contour Lines of Stevens County, MN

This map displays a National Elevation Dataset with the property lines of Stevens County, MN. Within the county are the city municipalities and elevation contour lines at 10 meter intervals.

Data Source: USGS and MN DNR Data Deli
Map Created: 11 August 2009 by Brittany Crocker
Figure 4.

Hillshade of Stevens County, MN

This map displays a hillshade analysis of Stevens County, MN. Within the county are the city municipalities.
Figure 5.

Slopes of Stevens County, MN

This map displays the slopes of Stevens County, MN represented in percentages. Within the county are the city municipalities.

Data Source: USGS and MN DNR Data Deli
Map Created: 11 August 2008 by Brittany Crocker
Aspects of Stevens County, MN

This map displays the aspects of Stevens County, MN. North has been defined as 0-45 and 315-360 degrees, East as 45-135 degrees, South as 135-225 degrees, and West as 225-315 degrees.

Data Source: USGS and MN DNR Data Deli
Map Created: 11 August 2009 by Brittany Crocker
Figure 7.

Example of Optimal Harvest Sites in Stevens County, MN

This map is an example of how GIS can be used to find optimal terrain for harvesting. Here the aspect, slope, and hillshade have been taken into account in Stevens County, MN. For this example the hypothetically optimal properties were a North aspect (0-90 and 270-359 percent), slope greater than or equal to 600.000 percent, and a hillshade value greater than or equal to 10. The spatial analyst raster calculator has found the places where these features all intersect. The sign-cue (1) is where all three of these features are found simultaneously, and the gray (0) are the places without all three of these features. Within the county lines are the city municipalities.
Figure 8.

10 Mile Buffer Zone Surrounding Morris, MN

This map shows the roads and cities within Stevens County, MN. A buffer zone was created around the approximate location of the biomass gasification plant in Morris, MN. This buffer zone has a radius of 10 miles.

Datum & Projection: NAD 83 UTM Zone 15
Data Source: MN DNR Data Deli
Map Created: 11 August 2008 by Brittany Crocker
**South Storage Lot**

<table>
<thead>
<tr>
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<th>Area (acres)</th>
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<tr>
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<td>0.11</td>
</tr>
<tr>
<td>Wood Chips 2</td>
<td>392.52</td>
<td>0.08</td>
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</tr>
<tr>
<td><strong>Remaining Unoccupied Space</strong></td>
<td>5,479.56</td>
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</tr>
</tbody>
</table>

This is the South storage lot for the feedstock used to fuel the biomass gasification plant in Morris, MN (within Stevens County). A Trimble Geographical Positioning System (GPS) was used to survey the site. The GPS was used to calculate the total area of the lot as well as each rowpile of feedstock. The GDS unit then calculated each of the areas, thus information was used to calculate the remaining space available within the lot. One additional space measured was the truck dugout (represented by the white rectangle) that was used for the trucks to back into for the purposes of dumping the wood chips.

Datum & Projection: NAD 83 UTM Zone 16
Data Source: MN Data Deli and Trimble GPS
Map Created: 14 July 2008 by Brittany Crocker
Figure 10.

North Storage Lot

<table>
<thead>
<tr>
<th>Item</th>
<th>Area (m²)</th>
<th>Area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire Lot</td>
<td>3131.61</td>
<td>0.77</td>
</tr>
<tr>
<td>Feedstock Row 1</td>
<td>347.81</td>
<td>0.09</td>
</tr>
<tr>
<td>Feedstock Row 2</td>
<td>482.52</td>
<td>0.11</td>
</tr>
<tr>
<td>Feedstock Row 3</td>
<td>486.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Total Occupied Space</td>
<td>1299.49</td>
<td>0.32</td>
</tr>
<tr>
<td>Total Unoccupied Space</td>
<td>1832.03</td>
<td>0.46</td>
</tr>
</tbody>
</table>

This is the North storage lot for the feedstock used to fuel the biomass gasification plant in Morris, MN (within Stevens County). A Trimble Geographical Positioning System (GPS) was used to survey the site. The GPS was used to calculate the total area of the lot as well as each of the three rows of bales. The GPS unit then calculated each of the areas; this information was used to calculate the remaining space available within the lot.
Acknowledgements

I thank the United States Department of Agriculture for providing the financial support for this project. I thank Mike Reese and Lowell Rasmussen for selecting this project to be funded. I thank Joel Tallaksen for choosing me to be a part of the biomass research internship team. I thank both Joel Tallaksen and Jim Barbour for their guidance throughout the project as well as for the experiences and knowledge they have passed on. I thank Curt Reese for letting me use the Trimble GPS equipment and for his help working with the software. I would also like to thank all of the staff at the West Central Research and Outreach Center for their general support and positive atmosphere.
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