Public Service Commission of Wisconsin
& The Statewide Energy Efficiency and Renewables Administration

Environmental and Economic Research and Development Program

Final Report

September 2010

Spatial Implications of a Wood Gasification System at UW-Stevens Point

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Acknowledgements

Dr. Anna Haines
Dr. Michael Demchik
Dr. Robert Govett
Eric Olson
John DuPlissis
Bob Oehler
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Lead Investigator
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Funding Provided By:
Focus on Energy

Center for Land Use Education Website:
http://www.uwsp.edu/CNR/landcenter/landcenter.html

Executive Summary

This report explains a new model for calculating logging residue availability in Wisconsin. The Center for Land Use Education and the College of Natural Resources at UWSP designed and performed this study to use Geographic Information Systems (GIS) technology to investigate biomass as a feedstock to replace UW-Stevens Point's coal and natural gas consumption.

The University of Wisconsin - Stevens Point (UWSP) presently consumes over 200,000 MMBtu equivalent of purchased electricity and nearly 250,000 MMBtu equivalent of non co-generation fixed energy to meet its annual operating needs (Oehler 2009). The UWSP stationary facility uses coal and natural gas to heat and cool the campus. Part of the rationale to examine this type of facility was prompted by the Governor's selection of UWSP as one of a handful of state-owned facilities that would plan for a more energy-independent future, and UWSP's previous chancellor signing the President's Climate Pact, which committed the campus to a carbon-neutral future. Therefore, to meet these goals, the campus is in the early stages of investigating a biomass facility that would reduce its demand for gas and coal.

Wisconsin has a large and diverse forest resource base that could potentially provide the campus with renewable energy. Feedstock for the campus's biomass energy production could come from the harvest of non-merchantable timber and/or harvest residues. Residues from logging operations include limbs, tops, small trees, and dead or dying trees. Following a timber harvest, forest residues typically are left on site because of their low economic value. Currently, there is only minimal published research that quantifies the amount of available harvest residue in the state. However, a large amount of proprietary research has been conducted in this area over larger regions of the northern portion of the state related to feedstock for planned facilities. To understand the ramifications of such a biomass facility on campus, we generated a spatially explicit dataset of potential timber harvest residue from various spatial and non-spatial databases. We used GIS software to translate biomass residue volume required by the campus into a plausible landscape scenario in central Wisconsin. We also identified and mapped different facilities that are currently using biomass resources for thermal heating, bioenergy production, and electricity as well as their supply distances. The amount and distance traveled for each facility were used as constraints in our model. The results of this study will help campus officials visualize the spatial distribution and abundance of timber harvest residue in Wisconsin and can be used to approximate a 'harvestshed' or the land area needed to meet projected feedstock demands. This project provides a model and template for other institutions and businesses considering the feasibility of bio-fuel projects. This model also can be used to understand competition among numerous facilities over the same biomass resources.

Our spatial approach to quantifying available harvest residue in Wisconsin is unique in that it generates a detailed map layer that depicts the potential oven dry tons of residue for the entire state while taking into account both environmental and physical constraints. Building the model in an ArcGIS framework allows the user to make changes, modify assumptions, and re-run it to produce multiple scenarios.

Key Findings

Factoring in harvest and resource demand constraints, our spatial model shows that Wisconsin generates 1.3 million oven dry tons of forest harvest residue annually. As a comparison, in 2008, the Wisconsin Department of Natural Resources (WI DNR) estimated that there was over 1.5 million dry tons of forest residue available at 70% recovery rate for the entire state. Using ArcGIS Network Analyst, we identified feedstock supply zones at 10-mile increments out to 100 miles from the campus's physical plant and summarized the potential availability of harvest residue in each zone. Presently, our campus is considering a 600 horsepower boiler system that could produce nearly all the steam needed, except on the coldest days. It is estimated that a boiler that size, running 50% green basis moisture content would consume about 34,000 green tons, or 17,000 oven dry tons of biomass per year. At that size, we estimate that our biomass "harvestshed" to be somewhere between 30-40 miles. The model we developed assumes that a biomass storage site would be located on the UWSP campus. However, due to space and delivery challenges, campus officials are considering an off-site aggregation yard where harvest material would be chipped and dried before transported to campus. The final location of such a site could dramatically change transportation costs and the harvestshed scenario presented here.

We set out in this research to explore the potential for regional availability of woody biomass resources and draw upon GIS technology to calculate the land area needed to meet the campus's renewable energy needs. We focused on a set of readily available data and expert professional advice from several disciplines to model the geographic distribution of biomass in Wisconsin. Our results look promising and are more spatially advanced than other methods. We show that there appears to be enough logging residue within 40 miles of campus to meet current energy demands. Interestingly, with UWSP's harvestshed completely within another user's source area, enough biomass material exists to meet energy needs.

The maps shown in this report provide a much more detailed picture of not only biomass resource exclusions, but also where possible extraction opportunities exist. The datasets generated from this research could be easily accessed and queried to measure and analyze a wide variety of woody biomass development scenarios.

Table of Contents

List of Figures

List of Tables

Introduction

Burning biomass for energy production is an important issue for energy policy in Wisconsin. The resurgent interest in renewable energy has been sparked by escalating energy costs and the public's growing concern about CO_2 emissions. State policies and the improving economics of renewable energy development have also accelerated the demand for energy from biomass (U.S. GAO 2006). A handful of states and communities have even agreed to energy portfolios requiring a certain fraction of consumption to come from renewable energy sources. The harvest of non-merchantable timber and the collection of harvest residues can be used to generate renewable energy, to reduce greenhouse gas emissions, to improve forest health, and to present economic opportunities to many rural communities in Wisconsin.

UWSP Energy Demand

The University of Wisconsin – Stevens Point (UWSP), located in central Wisconsin, is heavily reliant on coal and natural gas for its energy use. These sources are imported resulting in large amounts of money leaving the state. UWSP's stationary facility spends over $2 million annually on coal and natural gas to heat and cool the campus's 35 academic and residential buildings (Figure 1). Presently, UWSP consumes over 200,000 MMBtu equivalent of purchased electricity and nearly 250,000 MMBtu equivalent of non co-generation stationary energy to meet its annual operating needs [MMBtu = million Btu] (Oehler 2009). UWSP's projected energy demand is expected to increase because the campus has identified new building construction and other additions in its master plan over the next 15 – 20 years. These planned expansions will require an added 20,000 lb/hr of steam, 856 tons of chilled water, and 700 kW of electricity per year (Stanley Consultants 2008).

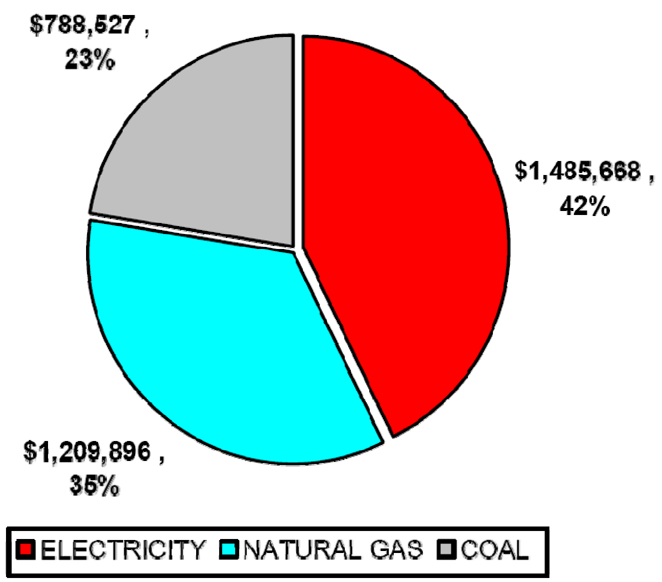

Figure 1. Current energy consumption by fuel type at UWSP.

The Governor selected UWSP as one of a handful of state-owned facilities that would plan for a more energy-independent future, and the former UWSP chancellor signed on to the President's Climate Pact, committing the campus to a carbon-neutral future. To meet these goals, the campus is in the early stages of investigating a biomass facility that would reduce demand for gas and coal.

It is important that campus officials understand the consequences of such a project now because UWSP as well as other campuses and facilities in and around Wisconsin are also seeking alternative energy options. With fast approaching voluntary timelines for reducing climate impacts, it is critical that we understand the ecological and economical consequences of such projects. There has already been a significant amount of time and expertise dedicated to the planning stages of a biomass fueled thermal facility on campus, including detailed study of the daily energy loads required by our operations.

UWSP began exploring more carbon neutral options in 2008. The campus is presently in the early stages of investigating a wood boiler to replace thermal demands presently met by fossil fuels. The campus also is committed to understanding the environmental and economic consequences of converting to a more climate friendly operation before committing public resources towards new technologies. New sources of biomass need to be identified because the current woody biomass resource appears to be fully utilized by existing mills (Perlack, Wright et al. 2005).

Forest Biomass
Wood is the most abundant biomass resource in Wisconsin (OEI 2008). Forest biomass, defined as the by-product of timber harvest operations, hazardous fuel treatments including trees and woody plants (limbs, tops, needles, and leaves), is a renewable energy resource that is clean burning, local, and environmentally safe (Forest Products Laboratory 2004). Woody biomass can come from merchantable or non-merchantable timber, harvesting residues, mill residues, urban and municipal waste, and short rotation woody crops (Milbrandt 2005; Perlack, Wright et al. 2005; Dickerson, Rubin et al. 2007). Logging residues, or slash, is the material left after a timber harvest and represents the largest available source of woody biomass. The Billion Ton Report, a Department of Energy study to determine if there are sufficient U.S. land resources capable of producing a sustainable supply of biomass for energy production, estimated over 67 million dry tons of logging residue is generated annually in the U.S. alone (Perlack, Wright et al. 2005).

While supplier markets for alternative energy sources will undoubtedly become available with increases in energy consumption, the recent introduction of several biomass energy-production plants in the state may create competition for this resource. For example, Xcel Energy is moving forward, albeit slowly, to build a biomass gasification facility at its Ashland Bay Front site in northern Wisconsin, which would consume nearly 450,000 green tons of biomass feedstock per year (Content 2009). Domtar Corporation near Wausau is awaiting state approval to construct a $250 million biomass-fueled co-generation power plant that would generate nearly 50 megawatts of electricity and serve nearly 40,000 homes, trucking in biomass from as far away as 75 miles (WE Energies 2009).

Benefits of Biomass
There are many advantages to using biomass instead of the fossil fuels currently used for meeting energy needs. The benefits may vary depending on the intended use and the fuel source, but include, potential CO_2 reductions, energy cost savings – mostly over gas, local economic development, waste reduction, and a secure domestic fuel supply (Forest Products Laboratory

2004; NREL 2010). Generally, wood is a renewable resource if the site is sustainably managed as a working forest and not degraded by conversion to another land use or unsustainable harvest practices. Compared to coal, burning wood generates lower levels of greenhouse gases like sulfur, mercury, and nitrogen oxides. It is also considered carbon neutral because the carbon emitted from the burning of wood is already part of the current carbon cycle where over time growing forests would re-capture the carbon emitted by wood-burning facilities (Zhang, McKechnie et al. 2010). There is much debate over the neutrality of biomass combustion due to the carbon used in the harvesting and transporting of the material (Johnson 2009). Burning biomass also emits CO_2 back into the atmosphere at a higher rate than what seedlings and saplings can initially sequester. Over time, however, the re-growth of harvested forests sequester more carbon from the atmosphere than what was initially produced (Manomet Center for Conservation Sciences 2010). Because residues are primarily forest-based, rural communities tend to benefit most from increased demand for feedstocks. Therefore, the bioenergy supply chain has the potential to create jobs and strengthen local economies through the management, harvesting, transportation, aggregation, and feedstock processing (Perlack, Wright et al. 2005).

Challenges of Biomass

The expansion of a biomass energy industry has prompted concerns about intensified forest biomass removal and its impact on water, wildlife, biodiversity and site nutrients (Skog and Rosen 1997). There is a strong relationship between forest productivity and soils. Nutrient-rich soils enhance forest growth while infertile soils usually support less productive forests. Removing large quantities of biomass can deplete the soil, reducing quality and promoting erosion. This could hinder forest growth and productivity (Perlack, Wright et al. 2005). Fallen woody debris, such as limbs and leaf litter also provides important habitat for wildlife. When this material is taken from the forest floor, these animals become displaced and the threat of invasive species increases (EPA and NREL 2009).

The Wisconsin Department of Natural Resources (WDNR) has responded to these concerns by developing biomass-harvesting guidelines in 2009. The guidelines provide general and site specific recommendations that identify how much material can be harvested from a site. They also include provisions for the retention of woody biomass for the protection of wildlife habitat, diversity, and soil replenishment (WDNR 2009). The quantity of slash removal depends on site characteristics, like soil type, depth, and slope. This will ensure that enough biomass material remains for soil replenishment and habitat for small animals.

Existing concentrated sources, like mill wastes from primary and secondary wood manufacturing facilities, appear already to be fully utilized (Perlack, Wright et al. 2005). The remaining dispersed sources, like logging residues, traditionally have had little commercial value so removing and transporting it requires large expenditures in harvesting technology (skidders, feller-buncher, swath cutters), primary transport (moving harvest residue from point of cutting to roadside), and processing (chippers) (Rummer 2007). The shipping of biomass tends to be one of the highest costs, with a maximum hauling distance often quoted at 50 miles (EPA 2007).

Biomass Availability

Despite the growing interest in biomass energy production, the spatial distribution is still somewhat unclear. Reasonable estimates have been made of total residue associated with harvest recovered on a fractional basis. The primary difficulty of quantifying available biomass for energy production is the complexity of the forest products industry. The feasibility of energy generated from biomass largely depends on the availability and cost of woody biomass resources. Wisconsin is blessed with an abundance of forest resources with over 16 million acres of forestland (WDNR 2007). However, it is the economic availability, or delivered price for a given quantity, rather than the physical amount that is significant to the development of any bioenergy project (Becker, Skog et al. 2009). The biomass industry is extremely complex, consisting of both suppliers and consumers, from large operators to small private merchants, adding to the challenge of accurately estimating resources.

Most foresters use US Forest Service's online Forest Inventory and Analysis (FIA) database to estimate the amount of biomass at the county level. Other assessments of biomass availability estimate the total amount, or a portion of what is recoverable, based on some fraction of reported harvest activity in the US Forest Service's Timber Product Output (TPO) database within a given county (BRDI 2008; Becker, Skog et al. 2009; U.S. Forest Service 2009). The biomass maps produced by the National Renewable Energy Lab illustrate the quantity of forest residues based on the USDA Forest Service's Timber Product Out database (Figure 2). While helpful, the data are summarized at the county level, and assume that all available biomass can be harvested. A more complete measurement should look at reasonably available biomass by taking into account geographic factors that affect harvest residue availability, such as environmental, physical, and management constraints.

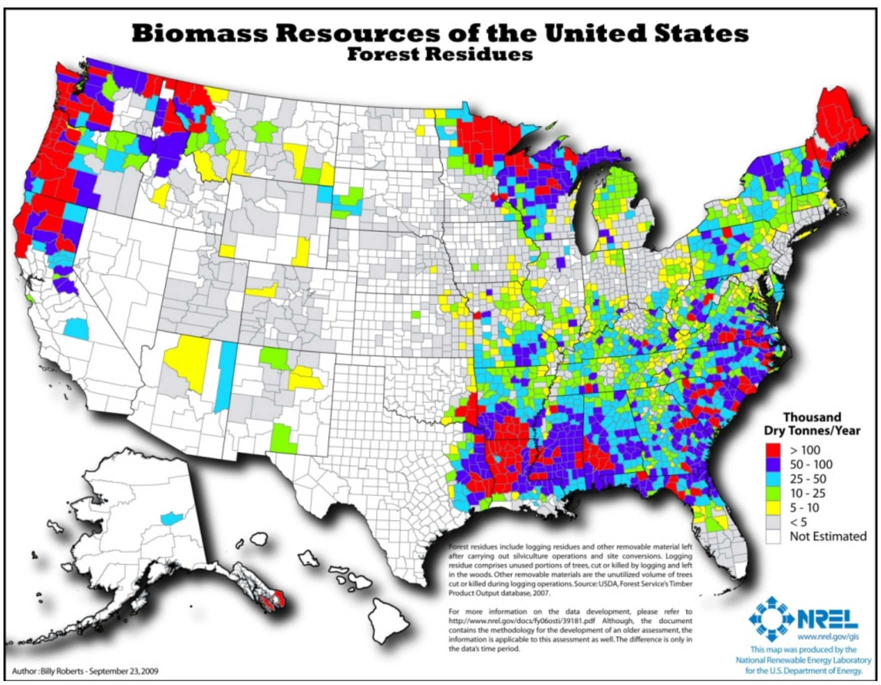

Figure 2. Biomass resource of the United States from National Renewable Energy Lab.

Many groups find it challenging to think about the range of spatial considerations associated with energy production and distribution. This challenge becomes even more obvious with increasing efforts to locate and implement renewable energy alternatives. It remains uncertain whether current and future biomass potential exists in central Wisconsin to support the campus's energy needs. This study helps lessen that uncertainty by providing campus officials with a model that looks at reasonably available biomass feedstocks. Though certain of the study's results are broadly applicable across the region, it is important to recognize that biomass availability largely depends on forest management practices of Wisconsin's landowners, which likely differ with the type of owner (public, private, industrial) and by region. Nonetheless, the framework and approach that we have developed for assessing biomass have wide applicability for other regions and states.

The purpose of this project was to determine UWSP's biomass "harvestshed", or the land area required to meet current energy demands. UWSP is located in an important timber producing and forest products manufacturing region. Working with spatial datasets, we developed a valid spatial model that uses real-world data and map algebra functions to derive an estimated harvest residue map of the state. The model is a new approach for calculating forest harvest residue using GIS technology. GIS provides a powerful way to combine data in a geographic framework to help answer questions about biomass feedstock availability in central Wisconsin. Our model uses various existing digital databases and layers from reliable inventories and sources. The methodology we developed is a means to extrapolate dependable information that is generally limited in areal coverage to a regional-scale of biomass supplies.

Methods
This study examined the potential availability of logging residue in Wisconsin, particularly within a specific travel distance from UWSP using Geographic Information Systems (Figure 3). We compiled, estimated, and summarized potential forest residues for the entire state of Wisconsin at a resolution of 30 meters. We also conducted a transportation network analysis to determine residue potential that exists within specific distances from the campus's stationary facility. This step aided in the visualization and assessment of local biomass resources. Located along the Wisconsin River and on the edge of the tension zone, considerable potential exists in the region for energy production from woody biomass; however, the projected demand for forest biomass resources is expected to increase due to the number of new facilities seeking to include more renewable energy sources.

Figure 3. Location of UWSP.

This study was designed to provide a fine spatial resolution through the use of both spatial and tabular databases from a variety of local, regional, state, and federal sources. Because we used GIS to model biomass availability, our results are interactive and visual. All datasets were projected into Transverse Mercator Projection, GCS North American 1983. We used ArcGIS version 9.3 for all analysis and modeling.   Table 1 lists the datasets used to estimate the spatial distribution of harvest residue and to delineate management, administrative, and environmental constraints on biomass removal.

Table 1. List of datasets used in the analysis.

Name	Type	Scale	Source	Year
National Land Cover Dataset	Raster	30 meter	USGS	2001
Road Centerline data	Vector	Various	WI Department of Transportation	2003
National Forest Lands	Vector	1:24,000	US Forest Service	Unknown
State Forest Lands	Vector	1:24,000	WI Department of Natural Resources	2000
County Forest Lands	Vector	1:24,000	WI Department of Natural Resources	2004
Managed Forest Lands	Vector	1:24,000	WI Department of Natural Resources	2003
Forest Crop Lands	Vector	1:24,000	WI Department of Natural Resources	
Protected Areas Database	Vector	1:24,000	USGS	2009
Urban Areas	Vector	1:100,000	US Census Bureau	2000
Forest Inventory and Analysis Plot Locations	Vector	Various	US Forest Service	2009
Surface Water	Vector	1:24,000	WI Department of Natural Resources (v6)	2007
County Boundaries	Vector	1:24,000	US Census Bureau	1990
Soil Limitations	Vector	1:20,000	NRCS	2004
Timber Product Output Database	Tabular	NA	US Forest Service	2009

Forest Cover

The first step in the analysis was to identify existing forest cover in Wisconsin. We utilized the USGS 2001 National Land Cover Dataset because it is the most recent national land cover layer; it extends the entire conterminous U.S., and is publicly available. The Landsat image-based land cover has a spatial resolution of 30 meters and provides categorical information on proportional cover types, such as forest, shrubland, wetland, and urban/barren lands. Forested pixels are broken up by type and include deciduous, evergreen, mixed, and woody wetlands. From this layer, we extracted forested pixels and then clipped the resulting image to the Wisconsin boundary. We then removed urban areas and small isolated patches of forestland (patches <10 acres). Doing this, we removed forested tracts that are not likely to be managed for long-term timber production (Gobster and Rickenbach 2004). The total amount of forestland in the entire state, according to the NLCD, is 16.8 million acres. When we remove urban areas and small isolated forest patches, the remaining forested acres is reduced to 14.5 million acres. A small amount of biomass material may be available within these extracted areas, but for the most part, they are not reliable, long-term sources for bioenergy production.

Biomass Energy Potential

Biomass conversion ratios were used to generate a pixel-level layer of expected oven dry tons of residue per cord (Demchik 2008). This step was accomplished by calculating a weighted average of wood harvested by species type according to the 2008 TPO database and then aggregating the results by the major forest cover types (Figure 4). As expected, evergreen species generally have a lower energy value than hardwood and mixed forests. We then used the energy ratios as a means for reclassifying the forestland cover grid. The resulting layer has a spatial resolution of 30-meters with each forest pixel representing the number of oven dry tons per cord of wood harvested (Figure 5).

TPO Forest Species

Species	oven dry tons/cord	Sample size
Balsam	0.31±0.02	39
Jack Pine	0.39±0.08	51
Red Pine	0.29±0.03	64
White Pine	0.27±0.03	66
Spruce	0.39±0.01	56
Ash	0.56±0.03	72
Aspen	0.70±0.13	69
Basswood	0.59±0.16	71
Black cherry	1.08±0.39	67
Hard maple	0.61±0.02	71
Soft maple	0.50±0.02	71
Select red oak	0.47±0.03	71
Other red oak	0.57±0.03	60
White oak	0.57±0.03	72

NLCD Forest Types

Species Group	Oven Dry Tons/Cord
Evergreen Forest	0.32
Deciduous Forest	0.60
Mixed Forest	0.55
Woody Wetlands	0.39

Figure 4. Ratio of oven dry tons of residue per cord of harvested timber for all species present in the TPO (left) and our aggregated energy ratios for forest cover types present in the NLCD (right).

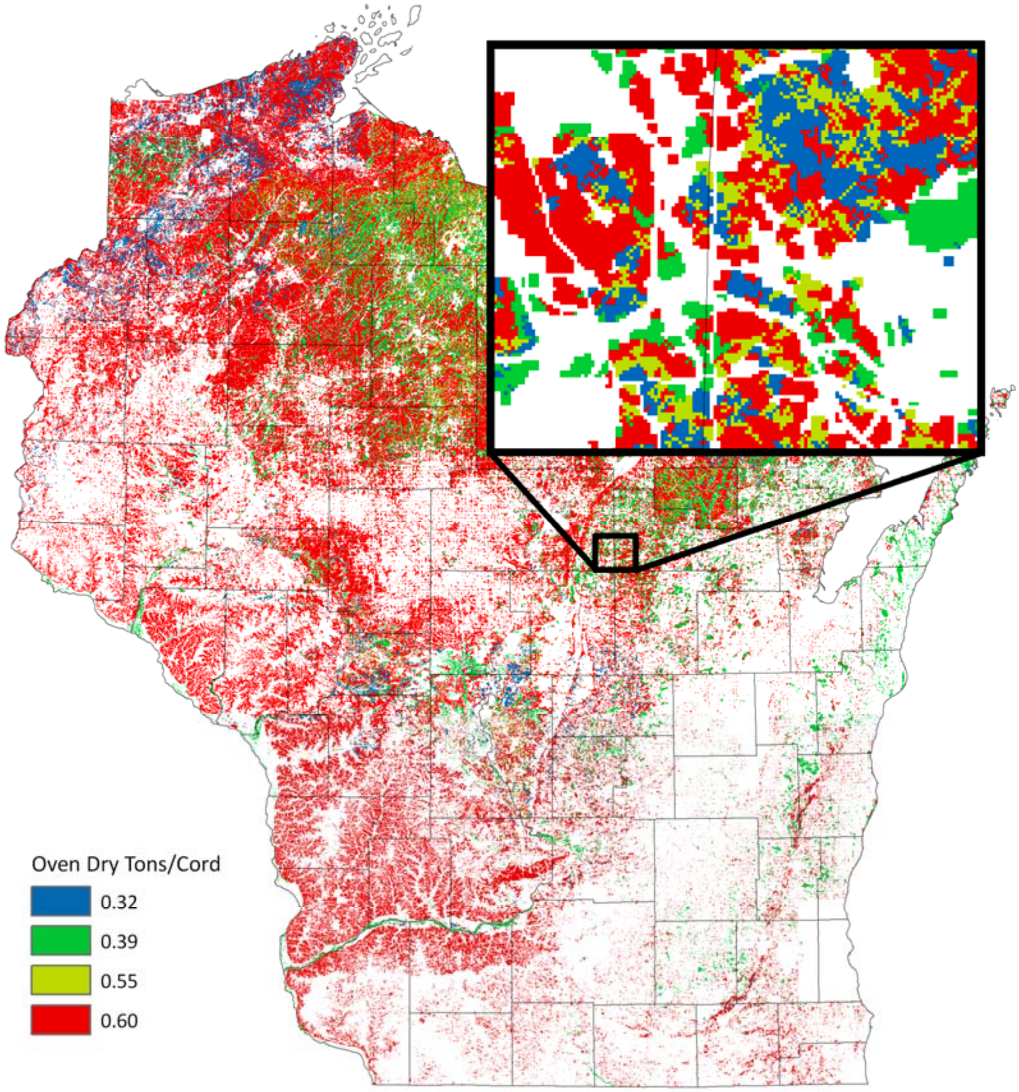

Figure 5. Wisconsin harvest residue energy potential (dry tons/cord).

Forest Growth

The US Forest Service FIA program conducts inventories of the Nation's forests through ground plots in which forest composition and structure are measure to produce estimates of woodland attributes like volume, basal area, growth, and biomass. Plots are systematically distributed about every 6,000 acres across parts of the country and each plot is visited every 5 – 20 years. FIA plot data is publicly available, but the georeferenced locations are slightly skewed for privacy concerns. We collected forest site data between 1999 and 2008 for plots in Wisconsin and from sites within 5 miles of the state border from Minnesota, Michigan, Iowa, and Illinois. Figure 6 illustrates the approximate geographic location of FIA plots (Figure 6).

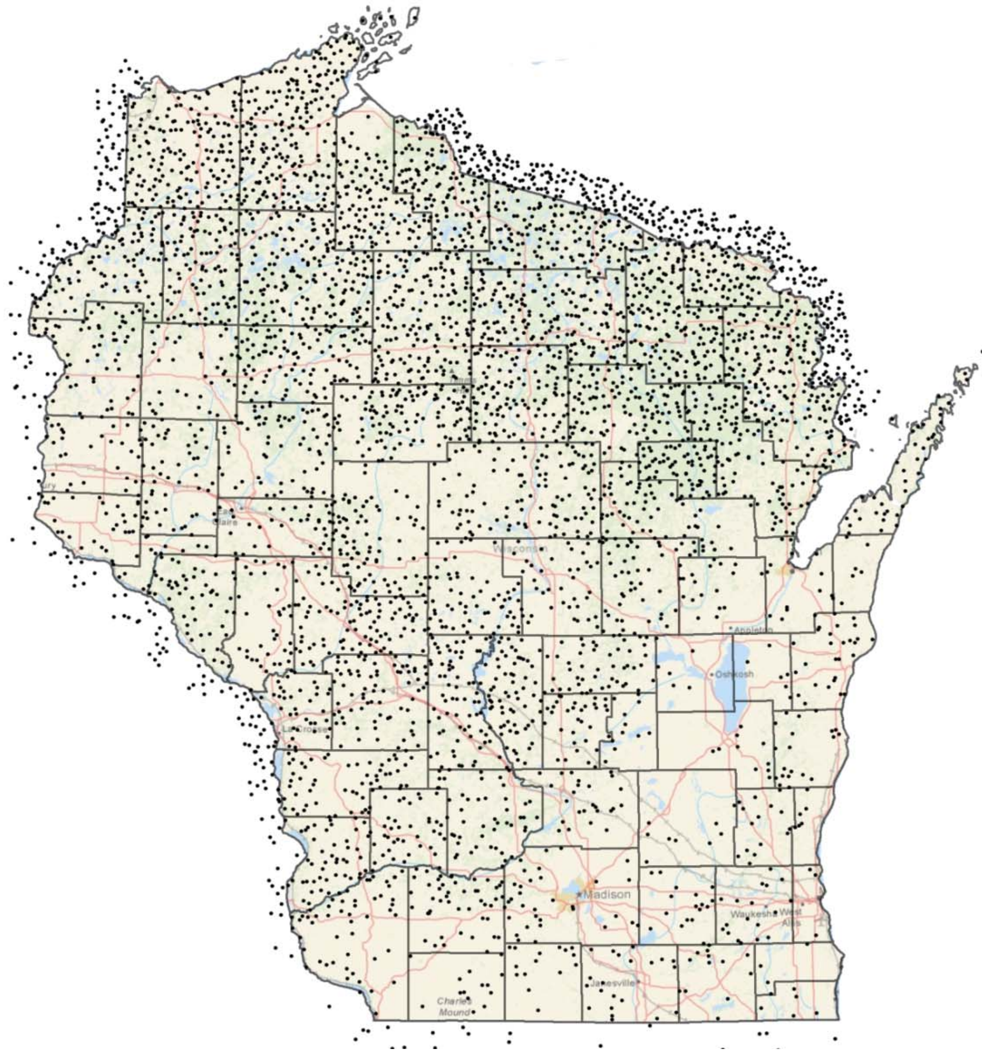

Figure 6. Approximate locations of FIA plots in Wisconsin and within 5 miles of the border.

The US Forest Service classifies these plot locations into six productivity classes that represent the culmination of average annual volume of wood growth in fully stocked stands. For our analysis, we took the average of each productivity class; except for the highest class, we used the minimum value to avoid overestimation (Table **2**). We then performed a geostatistical technique called Kriging to estimate expected values of forest growth (ft^3/acre/year), based on our FIA plot data points following the methods developed by Bridges (2008). Kriging is a spatial interpolation technique that researchers often use to predict values at non-sampled locations to create a continuous surface. To create a surface of predicted values, our kriging method makes predictions in the study area based on the relationship between FIA plot values as well as the spatial arrangement of measured values nearby. The result of this analysis shows the range in forest growth across Wisconsin (Figure 7).

Table 2. Forest Inventory and Analysis (FIA) productivity classes.

FIA Productivity Class	FIA class Ft³/ac/yr	Value used in analysis	Number of plots in study area
1	>224	225	3
2	164-224	194	15
3	120-164	142	218
4	85-119	102	1,124
5	50-84	67	2,045
6	20-49	35	1,507
7	0-19	10	51

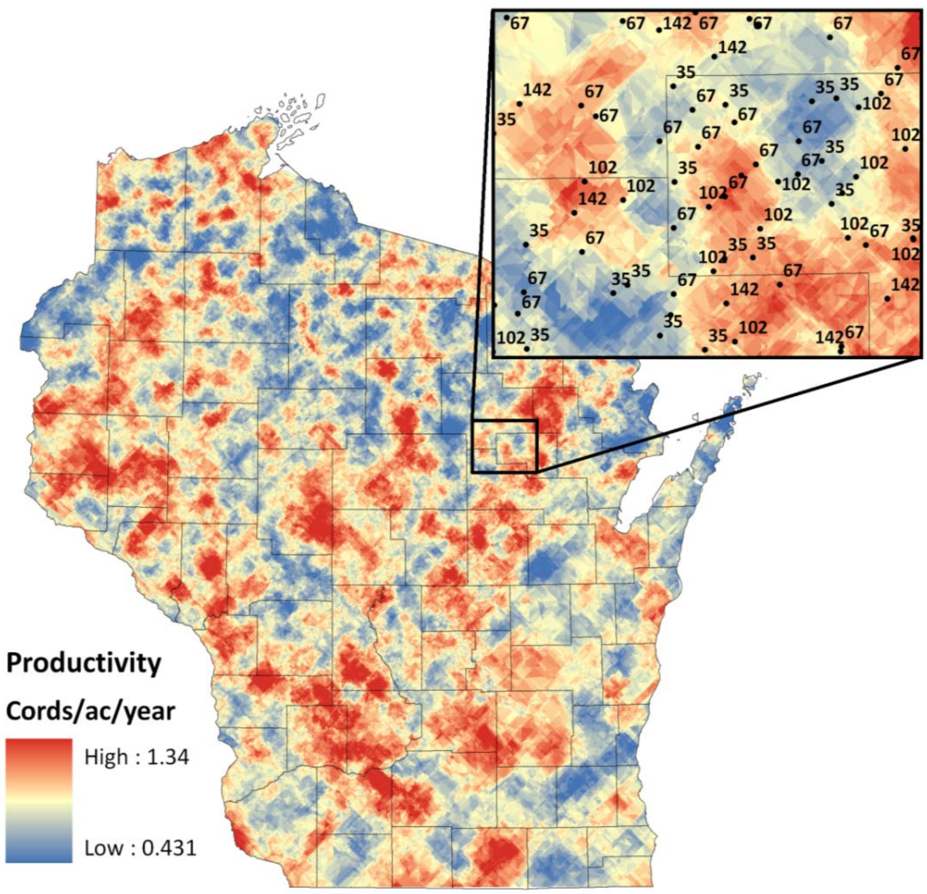

Figure 7. Estimated forest site productivity in Wisconsin.

Management Practices

Forest management practices depend on a combination of physical, biological, and economic factors (Newman 1988). Determining optimal rotation length and intermediate thinnings are dependent upon the site, species, and goal of the landowner. For this study, we applied common rotation lengths and number of normal thinnings for each species found in the 2008 TPO database (Demchik 2009). Once again, we calculated a weighted average based on the amount harvested by each species and aggregated the results to our major forest cover types: deciduous, evergreen, mixed, woody wetlands (Table **3**).

Table 3. Common rotation lengths and number of intermediate thinning by forest type (left). Aggregated rotation and thinning by major forest type (right)

Species	Cords Harvested	Rotation	Thinnings
Balsam	37,961	50	
Jack Pine	70,020	70	
Red Pine	132,813	90	3
White Pine	37,039	120	3
Spruce	29,282	70	3
Ash	53,045	80	2
Aspen	445,387	50	
Basswood	63,034	80	2
Black cherry	271,689	120	
Hard maple	206,935	70	2
Soft maple	153,787	80	3
Select red oak	61,441	80	3
Other red oak	54,309	80	3
White oak	37,961	50	

Species Group	Rotation	Thinnings
Coniferous	82.21	1.7
Deciduous	76.07	1.9
Mixed	77.23	1.8
Woody Wetlands	70.00	3.0

Land Ownership

Harvest residues are likely to come from integrated harvest operations. Timber harvest operations are also largely dependent upon the type of forest owner. We modeled willingness to harvest based on the different types of landowners found in Wisconsin. Data from various sources on land ownership boundaries were combined into one layer. We then assigned fractions based on landownership type (federal, state, county, tribal, MFL, Industrial, and private) that represent the likelihood of harvest operation. We used both published material and professional opinions for assigning willingness to harvest percentages (Becker, Skog et al. 2009; Demchik 2009; Govett 2009). Harvest residue was estimated as a portion of biomass coming from logging operations over the course of the rotation length. Figure 8 illustrates current land ownership patterns in Wisconsin and the associated willingness that we applied to each type of landowner. As Figure 8 depicts, private individuals own the majority of Wisconsin's forestland and will play a critical role in the availability of biomass resources.

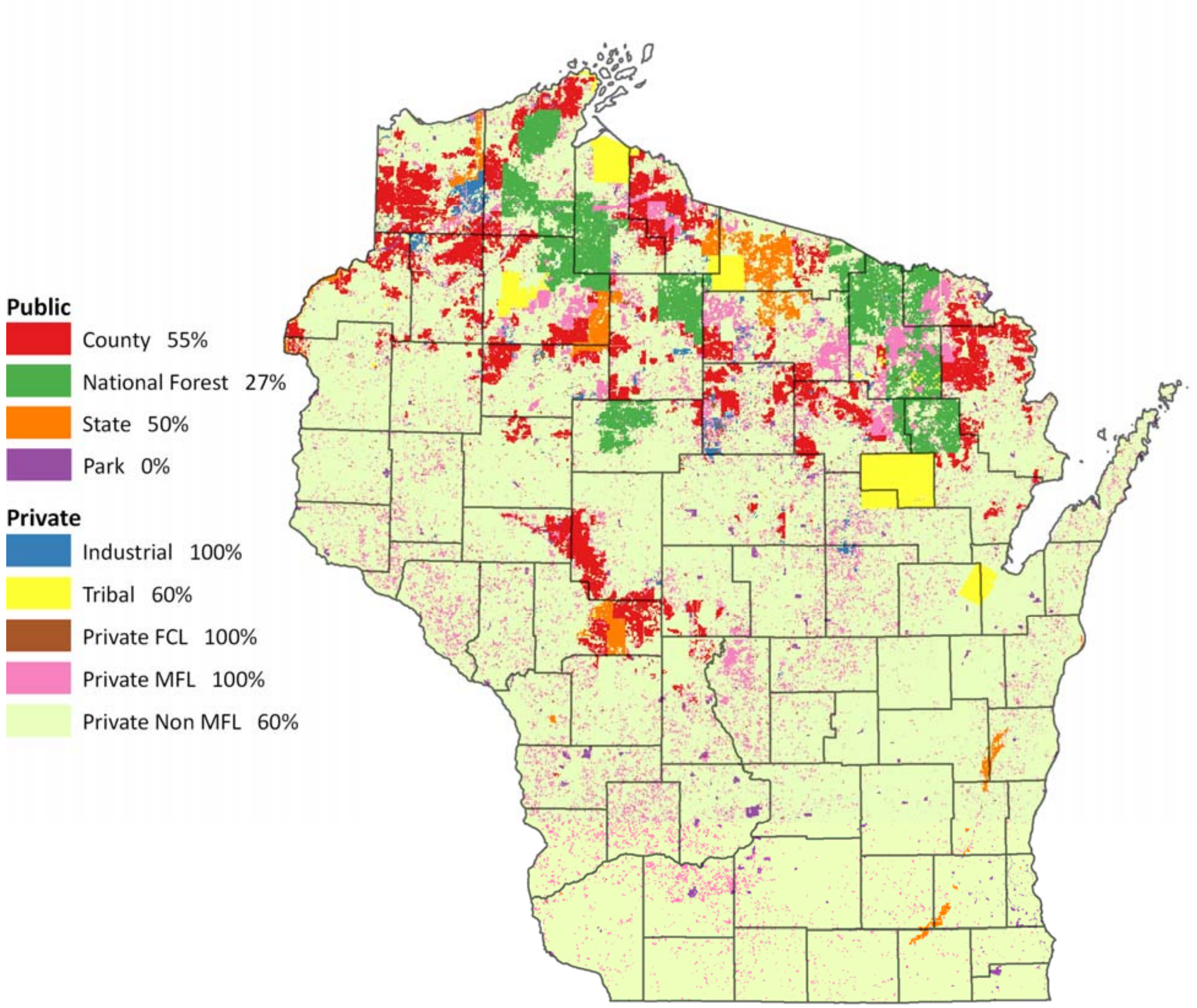

Figure 8. Landownership boundaries in Wisconsin and the percent willingness to harvest.

DNR Harvesting Guidelines

Due to the increased focus on harvesting woody biomass for energy production, the WI DNR has published guidelines for the sustainable harvesting of biomass resources. The guidelines were developed by professionals from a variety disciplines and groups to provide advice on how to remove woody biomass and how much should be left in the forests for healthy soils, wildlife habitat, and other ecosystem functions (WDNR 2008). A major focus of Wisconsin's biomass guidelines is the identification of soil types, such as sandy, wetland, shallow, and nutrient poor. Appendix D of the harvesting guidelines lists the soil types in Wisconsin that are considered to have biomass removal limitations. The list is organized by county and includes map unit names, symbols, limited components, limitations, and the percent of the soil type that is limited to biomass removal. From this list, we were able to map soil limitations by linking the table to the NRCS GIS soils layer. We assigned soils with no limitations a 90 percent harvestable rate because the guidelines require that approximately 10 percent of all harvestable material be retained on-site. Otherwise, we reduced the amount of recoverable material by the percent of map unit with limitations (Table 4). Figure 9 illustrates the percent of recoverable harvest residue in the state and shows that a majority of the land base has little or soil restrictions.

Table 4

Soil Map Units Limited by Biomass Harvesting Guidelines - July 2009					
Note: This list will be updated periodically to reflect new information from soil survey updates being conducted in Wisconsin by the Natural Resources Conservation Service.					
County	Map unit name	Map unit symbol	Limited component(s)	Reason for limitation	Percent of map unit
Adams	Boone sand, 2 to 6 % slopes	BnB	Boone	Dry Nutrient-Poor Sand	100
Adams	Boone sand, 6 to 12 % slopes	BnC	Boone	Dry Nutrient-Poor Sand	100
Adams	Boone sand, 12 to 25 % slopes	BnD	Boone	Dry Nutrient-Poor Sand	100
Adams	Boone-Rock outcrop complex, 25 to 45 % slopes	BpF	Boone	Dry Nutrient-Poor Sand	60
Adams	Plainfield sand, 0 to 2 % slopes	PfA	Plainfield	Dry Nutrient-Poor Sand	100
Adams	Plainfield sand, 2 to 6 % slopes	PfB	Plainfield	Dry Nutrient-Poor Sand	100
Adams	Plainfield sand, 6 to 12 % slopes	PfC	Plainfield	Dry Nutrient-Poor Sand	100
Adams	Plainfield sand, 12 to 35 % slopes	PfD	Plainfield	Dry Nutrient-Poor Sand	100

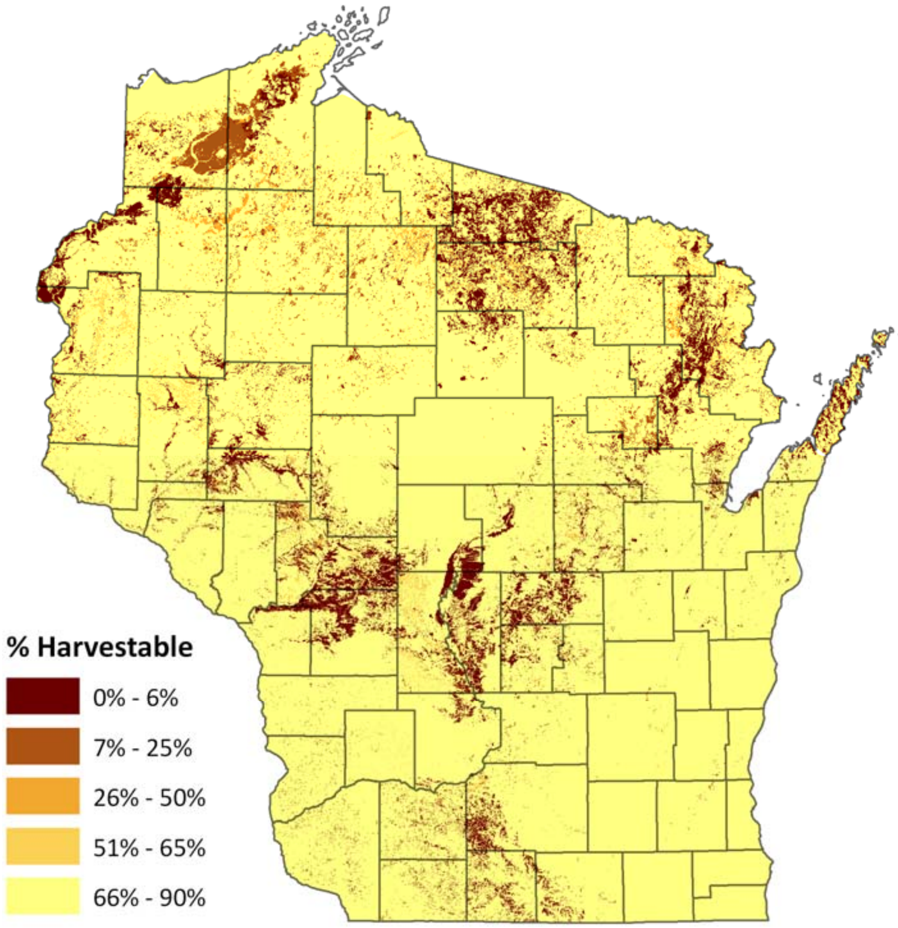

Figure 9. Soil limitations for recoverable logging residue based on the WI DNR's harvesting guidelines.

Ecological Constraints
The WI DNR has established best management practices for forestry activities within close proximity of water features to protect the functions and values of riparian areas. Forestry practices are modified to protect water quality, fish and wildlife habitat, and aesthetic values

within riparian management zones (RMZs). For this research, we utilized the WI DNR vector hydro layer to model RMZs. We buffered water features by 50 feet and converted the results to a raster format. The resulting grid was used as a constraint in the final model.

Competing Biomass Users
UWSP forestry students collected current industry usage of biomass resources in 2008/09 to estimate the amount of bioenergy production in Wisconsin. Only 44 facilities were willing to share information at the time of the survey. Students compiled data on the type of biomass fuel (wood, bark, sawdust), annual amount utilized in tons, and supply distance traveled in miles. We mapped facilities by converting each address to a specific point location, also known as geocoding. Using a road network of Wisconsin, we measured the maximum travel distance for each facility and applied the amount of biomass consumed to the resulting buffer as a constraint to the final model. The intended use of the original survey data prohibits us from listing the amount of biomass being used by each facility and their hauling distance. Figure 10 illustrates the location of some existing facilities using biomass for energy production in the state.

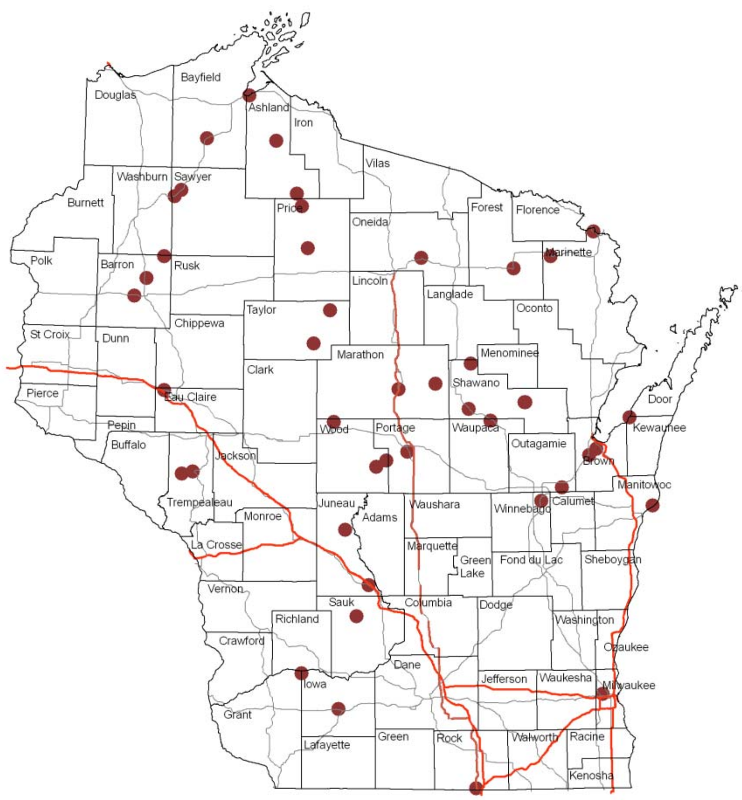

Figure 10. Facilities in Wisconsin that use biomass for energy production.

Logger Willingness
A major uncertainty in the availability of biomass resource is the willingness of loggers to collect the leftover material. Some loggers have adapted their operations to harvest logging residues in addition to conventional roundwood products, but it remains unclear as to how many are willing to adapt. Anecdotal evidence suggests that roughly half of the logging operations, especially those where strong biomass markets exists, are willing to gather biomass for energy production in addition to their conventional roundwood harvest efforts (DuPlissis 2009).

Proximity to UWSP
Transportation costs of biomass resources are generally a great concern to users. We used a Wisconsin road layer and ArcGIS Network Analyst to calculate travel distances from the UWSP transfer facility. Service area polygons were generated at 10-mile increments out to 100 miles (Figure 11). We used the buffers of this analysis to summarize the amount of biomass residue and to calculate the general distance UWSP would need to travel meet its bioenergy demand.

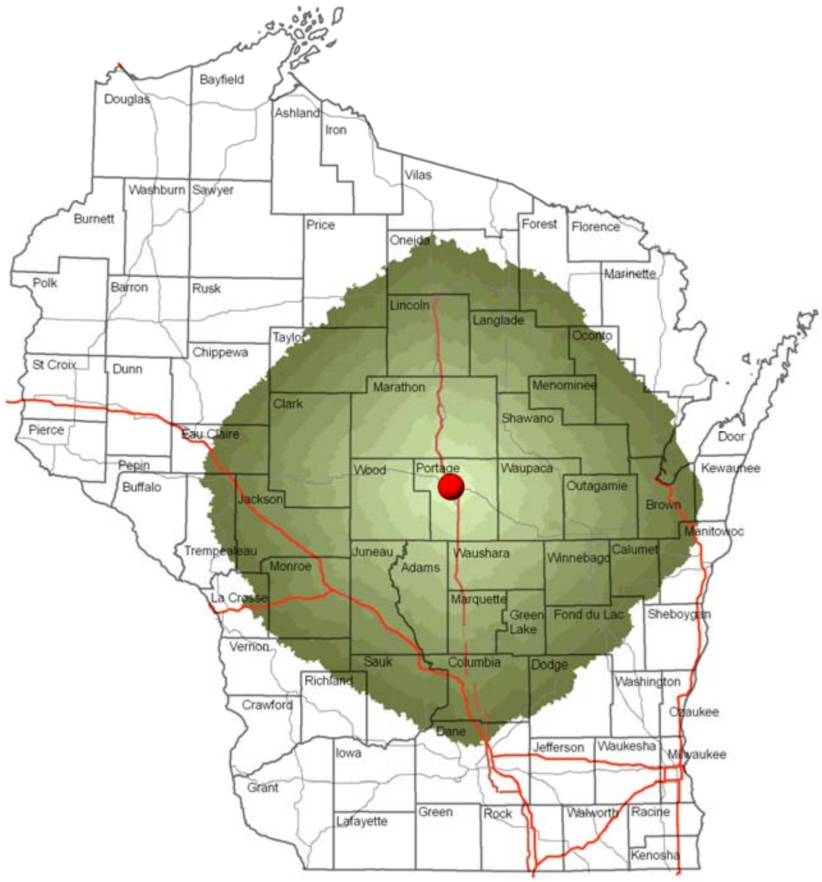

Figure 11. Source area buffers determined by ArcGIS Network Analyst from UWSP in 10-mile increments.

Model Development
Our conceptual model for estimating harvest residue is as follows:

$$Available\ Residue = f\{growth, harvest\ specifications, proportion\ harvestable,\\ landowner\ willingness, logger\ willingness, already\ used\ residue\}$$

We used ArcGIS ModelBuilder and map algebra language to build complex expressions and processes for running the model. ModelBuilder is an application within ArcGIS that allows the user to automate and preserve tasks and workflows. Using this method, we were able to create processes and immediately run them in ModelBuilder to see the results. More importantly, we were able to modify parameters, re-run the processes, and visualize the alternative scenarios on a map. Figure 12 illustrates our model in graphical form in ArcGIS ModelBuilder.

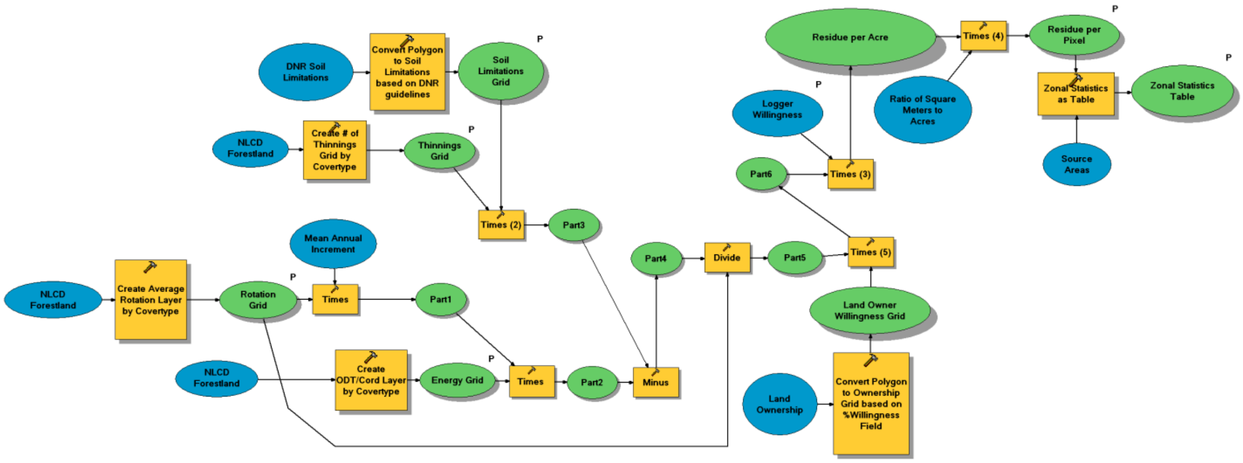

Figure 12. ArcGIS ModelBuilder diagram representing the geoprocessing workflow with multiple processes strung together (also see Appendix A).

The diagram in Figure 12 in equation format looks like this:

> ({[Ratio of energy wood to cord X (Growth in cords X Average rotation length for species cover type)] - (# of normal thinnings for cover type X (Difference between DNR BMP residue requirement and estimated normal CWD on site by cover type))} / Avg rotation length) X Landowner Willingness X Logger Willingness

Results

We used a general approach to quantify the amount of available logging residue for bioenergy production in the state using GIS technology. Figure 13 illustrates the results of our spatial model. The spatial resolution of the final map is 30 meters with each pixel representing the estimated amount of annual residue in oven dry tons. One can see that the geographic distribution of potentially available biomass is spread throughout the northern, western, and central part of the state and range from a minimum of zero to a maximum of 0.09 oven dry tons.

We verified the accuracy of our model by comparing our results to the 2008 TPO estimated logging residue numbers at the county and state level shown in Table 5. We used a 65 percent recoverable rate to calculate the TPO harvest residue numbers. The results of our model, when aggregated at the county level, indicate that there is a close relationship between both methods. The variation between methods was overall low for most counties, but was higher with those that are larger and have abundant forestland. This can be expected because of the variation in physical and environmental constraints within those counties. As a whole, we estimate there to be over 1.3 million oven dry tons of reasonably collectable harvest residue generated annually in Wisconsin, compared to the 1.5 million from the TPO database.

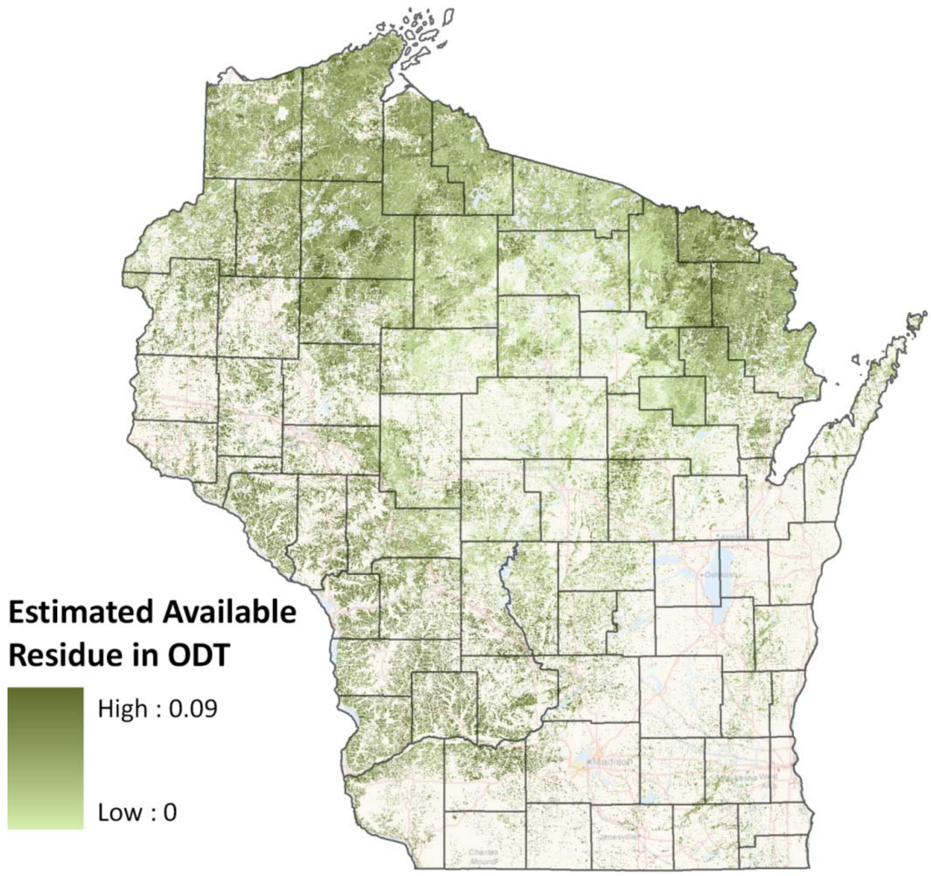

Figure 13. Pixel-level forest harvest residue (oven dry tons)

Table 5. Comparison between TPO county level logging residues and CLUE GIS model.

County	TPO Logging Residue @ 65%	GIS Model Estimates	County	TPO Logging Residue @ 65%	GIS Model Estimates
Adams	21,583	16,207	*Marathon*	52,200	11,721
Ashland	79,115	54,854	*Marinette*	64,884	68,700
Barron	19,780	22,238	*Marquette*	4,042	8,239
Bayfield	61,759	86,812	*Menominee*	32,414	7,745
Brown	2,245	2,635	*Milwaukee*	46	-
Buffalo	11,448	28,227	*Monroe*	17,224	28,629
Burnett	20,439	27,193	*Oconto*	36,999	32,226
Calumet	1,056	1,142	*Oneida*	64,400	21,754
Chippewa	19,351	27,488	*Outagamie*	3,106	3,975
Clark	29,933	21,846	*Ozaukee*	948	1,296
Columbia	4,380	10,581	*Pepin*	3,472	7,263
Crawford	9,745	21,299	*Pierce*	5,245	11,720
Dane	1,947	11,023	*Polk*	9,461	28,317
Dodge	1,787	2,964	*Portage*	17,500	8,337
Door	4,824	6,212	*Price*	52,729	36,867
Douglas	43,865	60,920	*Racine*	14	2,356
Dunn	14,271	23,263	*Richland*	14,102	23,861
Eau Claire	9,653	18,072	*Rock*	731	4,007
Florence	39,970	34,625	*Rusk*	40,640	43,001
Fond du Lac	1,075	3,626	*Sauk*	17,742	24,394
Forest	71,297	48,716	*Sawyer*	103,589	78,510
Grant	10,416	19,337	*Shawano*	40,821	11,851
Green	1,940	3,494	*Sheboygan*	3,240	4,738
Green Lake	664	2,651	*St. Croix*	4,014	9,964
Iowa	8,942	19,559	*Taylor*	33,764	12,452
Iron	34,048	36,086	*Trempealeau*	8,910	23,103
Jackson	31,293	31,546	*Vernon*	9,656	26,579
Jefferson	1,159	3,570	*Vilas*	38,438	30,443
Juneau	22,257	18,403	*Walworth*	179	4,911
Kenosha	712	1,569	*Washburn*	46,873	43,383
Kewaunee	3,880	2,012	*Washington*	1,180	4,038
La Crosse	5,797	17,552	*Waukesha*	319	4,006
Lafayette	974	3,022	*Waupaca*	16,540	13,386
Langlade	78,831	12,196	*Waushara*	18,078	8,808
Lincoln	53,854	12,607	*Winnebago*	384	1,167
Manitowoc	4,666	1,465	*Wood*	26,878	11,346
			Wisconsin	1,519,718	1,378,102

Figure 14 illustrates the cumulative oven dry tons of logging residue within 100 miles from UWSP. We show both the total (excluding competition) and available amount at measured driving distances from the campus. There is little residue within the first 10 miles, but availability steadily increases with distance.

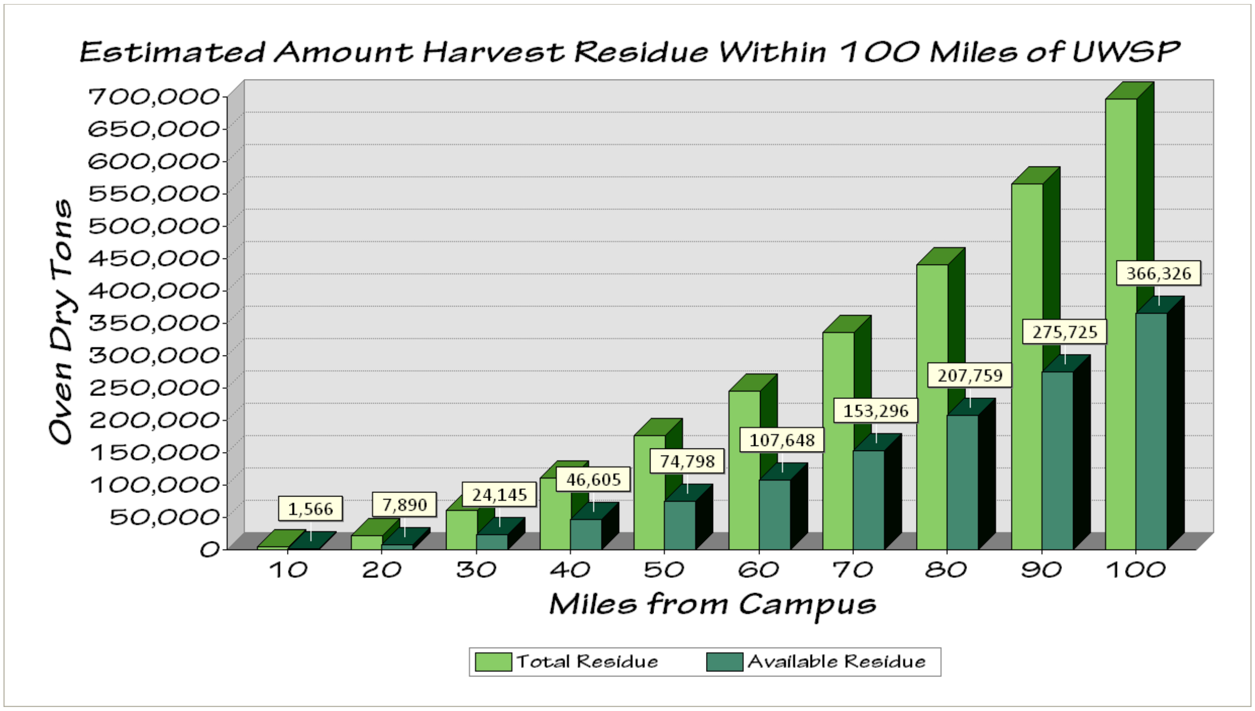

Figure 14. Estimated logging reside availability within 100 miles from UWSP.

Presently, our campus is considering a 600 horsepower, co-generation boiler system that could produce nearly all the steam needed, except on the coldest days. It is estimated that a boiler of that magnitude would consume about 34,000 green tons, or 17,000 oven dry tons of biomass per year. At that size, we estimate that our biomass "harvestshed" to be somewhere between 30-40 miles (Figure 15). Unlike other models, we added both environmental and physical constraints to estimate reasonably available biomass. Had we not included constraints in our model (riparian management zones, existing facilities using biomass, and soil limitations), it would appear that our campus would only need to travel half that distance to meet its energy demand.

Figure 15. UWSP estimated biomass harvestshed.

Discussion and Conclusion

Spatially explicit harvest residue information at a regional scale provides a unique perspective of how biomass is distributed across the state and provides reasonably accurate estimates for assessing quantity. We initiated this research project to explore the regional availability of woody biomass resources using GIS and to calculate the land area needed meet the campus's renewable energy needs. The results of this study indicate that local sources are adequate to support a sustainable biomass burning facility at UWSP. We focused on a set of readily available data and expert professional advice from several disciplines to model the geographic distribution of biomass in Wisconsin. Our results look promising and are more spatially advanced than previous studies. We show that there appears to be enough logging residue within 40 miles (nearly 47,000 oven dry tons) of campus to meet current energy demands. We also identified competing sources of biomass and showed that even with UWSP's harvestshed completely within other user's source area, there remained enough biomass material within close proximity to meet projected energy needs.

The maps shown in this report provide a much more detailed picture of not only where there biomass resource exclusions, but also where there are possible extraction opportunities. The datasets generated from this research could be routinely accessed and queried to measure and analyze a wide variety of woody biomass development scenarios. It should be noted that we made gross assumptions to estimate state volumes of available harvest residue. The results are not intended for site specific estimates, but could be used as a first analysis for demonstrating resource availability for an organization.

This study is provides a reasonable estimate of harvest volume. How this study could play in the real world is much more challenging. For example, the UWSP campus can only receive material during limited times of the day and has limited storage space. In addition, the wood residue will not be directly transported from the harvest site directly to campus on a routine basis; rather it would likely go to a concentration facility where it will age to reduce moisture content. The concentration yard will likely be located out of the campus area and dramatically alter transport economics. Currently, campus officials are considering a concentration yard location that would serve as a biomass staging area for multiple companion facilities, like UWSP and Domtar. This would radically change transportation costs because hauling trucks could be loaded both ways (bring in material for aging and removing chips for energy production).

This study is very specific to central Wisconsin and the Stevens Point area. A key issue in the area is the health of the forest products industry, particularly paper and pulp. During this study, the paper mill industries experienced large losses throughout 2009 and 2010. Harvest residue maps would look very different if one or more of the local paper mills closed because it would result in fewer trees being harvested from which biomass energy currently derived.

This model has shown promise as a means of using GIS as a tool for measuring the abundance and geographic distribution of biomass resources at a regional level. The overall performance of the application remains a useful approach to investigating biomass resources in Wisconsin and elsewhere. The analysis can be replicated for locations anywhere in the United States because we draw on publicly available resources. While this is a significant step in biomass availability research, future efforts are necessary to evaluate and compare this technique with actual forest site assessments. For example, our method of estimating for site productivity could be improved upon. Presently, NRCS soil data lacks forest site productivity estimates, but plans are underway to include that information in the Ssurgo database. We set up our analysis using ArcGIS ModelBuilder so that when new research becomes available, the model can be adjusted and re-run to produce on-the-fly results and alternative scenarios.

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Appendix A. ArcGIS ModelBuilding Cartographic Model