Usability of Forest Residue Biomass for Electric Utility Production in Wisconsin USA

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Abstract

A Geographic Information System (GIS) was used to estimate the amount of available forest residue biomass from timber harvests within the State of Wisconsin, USA and within a 50 mile radius of power plants that burn biomass for energy production. Publically available land cover, soil, and elevation data were used to ascertain the available forested areas for biomass harvest. Approximately 5.8 million oven dry tons of forest residue biomass are considered available statewide, the majority located in the northern part of the state. While further consideration should be done on a site by site basis, Wisconsin's forests hold the potential to aid in electric utility production.

Introduction

The push for sustainable energy in the last decade has sparked a governmental intervention promoting the use of alternative energy practices. Governor of Wisconsin, USA, Jim Doyle, under executive order #192, proposed a plan that stated 25% of the state's electricity would come from renewable resources by the year 2025 (Vigue, 2008). According to the Public Service Commission of Wisconsin (PSCW, 2010), 67.6% of the state's electric supply is derived from coal fired plants, 7.9% from natural gas, 0.8% from wind, 0.1% from fuel oil, 2.7% from hydro-electric, 19.1% from nuclear, and 2% from biomass.

Biomass for energy production is a renewable resource harvested from a variety of sources including brush, willow matter, crops, waste, timber, and forest residue (WI DNR, 2009). Instead of burning coal to generate electricity in a plant, biomass products are used, decreasing the need for fossil fuels and increasing use of renewable resources. Wood is a promising feedstock because it can be obtained from multiple sources, has multiple biological and thermochemical conversion pathways, and has the potential to produce a diverse array of products; the end product of interest for this study being electricity (Castellano, Volk, and Herrington, 2008). Additionally, wood biomass is less expensive than fossil fuels, the amount of carbon dioxide (CO^2) emitted during the burning process is typically 90% less than when burning fossil fuels, and wood contains minimal amounts of sulfur and heavy metals (Forest Products Laboratory, 2004).

Utilizing wood biomass for energy, measured in oven dry tons (2000 lbs. at 0% moisture content), can be done using various technologies. Wood combustion is the process of burning

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wood, in a variety of forms, to produce heat which then fires the boiler to produce steam. Turbines then convert the steam to electric power. Wood gasification involves heating wood in an oxygen starved environment until gases are released. The gases are then mixed with air for complete combustion and the heat transferred to a boiler for energy distribution. Cogeneration simultaneously produces heat and electricity. Lastly, co-firing refers to using biomass as a supplemental energy source in coal fired plants (Forest Products Laboratory, 2004).

There are however, a number of concerns associated with burning wood biomass to produce energy. One concern in using wood as a fuel, we reduce the amount of timberland available for carbon sequestration (WI DNR, 2009). Forest biomass, the aboveground portion of live trees, is linked to many forest ecosystem processes. Forests, aboveground and in the soil, are better at storing carbon than any other type of land cover (WI DNR, 2009). Terrestrial ecosystems, through growth and expansion, absorb between 15 – 40 % of annual human caused emissions of carbon to the atmosphere. Additionally, forests provide habitat for a variety of animals and plants and opportunity for recreational activities (Herrick, Kovack, Padley, Wagner, and Zastrow, 2009). Removing trees and litter by harvesting may reduce habitat and prevent essential nutrients from being absorbed by the soil. Other uses of the forest include preventing soil erosion, producing oxygen, providing outdoor recreation, reducing noise, and creating natural beauty.

The purpose of this study was to estimate and analyze the amount of residue generated by forest operations seeking the merchantable part of the tree and potential utilization in electric utility production following sustainable forestry practices.

Methods

Study Area

The State of Wisconsin houses more than 16 million acres of forestland accounting for more than 45% of state's total area (WI DNR, 2009). Industries associated with Wisconsin woodlands provide employment for approximately 65,000 people. Analysis on a state level was selected due to data availability and importance of the timber industry for Wisconsin's economy and forests.

Three locations of power plants that burn woody biomass for electric utility production were identified in this study: Bayfront in Ashland, French Island near La Crosse, and Stoneman in Cassville. A fourth power plant is proposed in Rothschild. Figure 1 shows the locations of these facilities and their respective generating capacity in MegaWatts (MW) (PSCW, 2010).

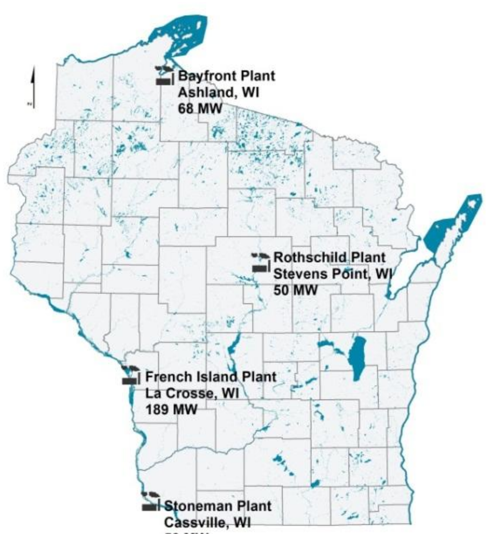

Figure 1. Biomass burning power plants in Wisconsin study area with county borders.

Criteria

Woody biomass for the purpose of this study is defined as wood materials, such as wood, bark, sawdust, forest residue, and mill scraps (Herrick et al., 2009). The interest here is forest residue biomass or biomass that is a bi-product of wood harvesting. Traditional timber harvests generally remove wood or biomass greater than five inches in diameter for hardwoods and four inches in diameter for softwoods. These merchantable portions are hauled away, leaving small branches and other bi-products at the harvest site. The amount of available biomass depends on factors that relate to the amount of residue generated from forest operations. Forest operations are influenced by a number of social, economic, and environmental factors (Herrick et al., 2009). According to these influences and based on guidelines developed by the Wisconsin Council on Forestry and the Wisconsin Department of Natural Resources and with figures collected by the Minnesota Department of Natural Resources the following criteria were selected to determine the potential of forest residue in electric utility production:

(1.) Areas of forest land type delineated by the Wisconsin Land Cover Grid (1999)
(2.) Areas of open water would not contain trees to harvest, open water was excluded.
(3.) Areas with slopes greater than or equal to 20% were excluded based on economic and environmental constraints.
(4.) Areas located on shallow soils where bedrock is within 20 inches of the surface were excluded due to high potential for erosion.
(5.) Areas located on dysic Histosols, or wetland soils, because of their nutrient rich nature for wetland habitat were excluded.
(6.) Areas located on dry, nutrient poor soils were excluded for harvest to retain as many nutrients as possible on these sites.
(7.) A radius of 50 miles extending from the utility plants was selected based on economic constraints.

Data for this study were obtained using public sources. All datasets were clipped to the state of Wisconsin and projected to the North American Datum of 1983 HARN Transverse Mercator adjustment. Table 1 displays the data used in this study organized by criteria.

Table 1. Criteria for forest residue in electric utility production estimation and analysis.

Criteria	**Subcriteria**	**Data**	**Data Source**
Land	Forest Type	Wisconsin Land Cover Grid, 1998	ftp://dnrftp01.wi.gov/geodata/landcover/
	Bodies of Water	Wisconsin Land Cover Grid, 1998	ftp://dnrftp01.wi.gov/geodata/landcover/
Soil	Shallow Soils	Soil Survey Geographic Database	http://datagateway.nrcs.usda.gov/
	Dry Sandy Soils	Soil Survey Geographic Database	http://datagateway.nrcs.usda.gov/
	dysic Histosols (Wetland Soils)	Soil Survey Geographic Database	http://datagateway.nrcs.usda.gov/
Slope	Less than or equal to 20%	Digital Elevation Model of Wisconsin	ftp://dnrftp01.wi.gov/geodata/elevation/
Facility	50 mile radius	Wisconsin Plants	Public Service Commission of Wisconsin

Limitations

This study does not address parcels of land that are not accessible for timber harvest. For example, owner opinions, protected areas, negative ownerships, riparian management zones, and lands deemed as High Conservation Value Forests are other factors that may play a role in harvesting a specific site are not considered (Herrick et al., 2009). This study is intended as a general view in quantifying forest residue biomass for energy production based on land cover type. Further analysis should be completed on a site by site basis and take into consideration silvicultural practices based on tree species, age, diameter at breast height (dbh), volume, and stand demographics. Such data on a state scale was not publicly available at the time this study was completed.

Procedure

All spatial datasets were processed using ArcGIS version 10 authored by the Environmental Systems Research Institute, Inc. (ESRI, 2010), in conjunction with Microsoft Excel (2010) to evaluate tabular data associated with the various datasets.

Criteria Classification

Land Type

Using the Wisconsin Land Cover Grid, areas of timberland were selected and reclassified using the Spatial Analyst Toolbar (ESRI, 2010). Three cover types were chosen: Aspen-Birch-Balsam-Poplar, Hardwoods, Conifers, and identified in the forest cover raster as values 1, 2, and 3, respectively (MN DNR, 2010). Areas not designated as forest cover and areas of open water were assigned a value of 0 during this operation. Figure 2 shows a subset of the locations of 30 x 30 meter stands of forest cover by type.

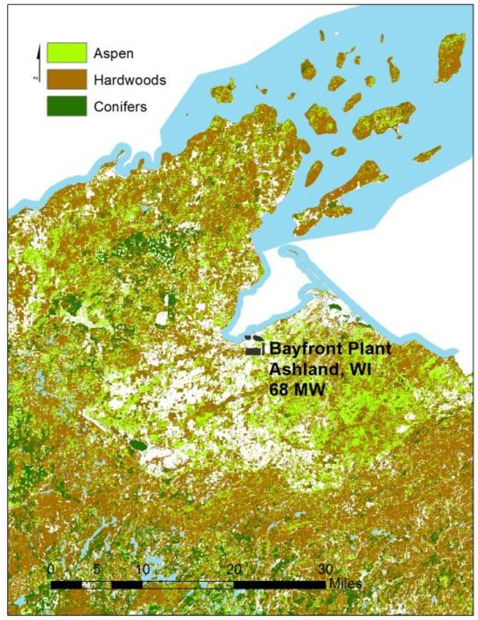

Figure 2. Areas of timberland by forest type near the Bayfront Plant, Ashland, WI.

Data collected and developed by the Minnesota DNR include coarse and fine woody debris generated by harvest operations over multiple sites aggregated to an area of approximately 4,000 acres (MN DNR, 2006). Calculations were further refined for each forest cover type for application in Wisconsin. Reciprocity of these values are based on the similar geography, climate, and vegetation of each state. Values used for analysis are shown in Table 2.

Table 2. Amount of forest residue generated by generalized forest type.

Forest Type	Cords per Acre	Cords per 30x30 m cell ($900m^2$)
Aspen	5.7	1.27
Hardwoods	7.54	1.68
Conifers	4.5	1

To convert cords to oven dry tons the following conversion was used:

1 cord = 1.2 oven dry tons (US)

Soil Type

Areas with shallow soils, where bedrock occurs at 20 inches or less from the soil surface, were deemed non-harvestable areas. Soils of a 20 inch depth until reaching bedrock contain half of the nutrient supply of a deep soil (topsoil of 40 inches or more). With repeated harvests, these areas are more likely to show nutrient depletion. Dry sandy soils are also identified as nutrient poor, as they lack clay content, have a low pH, and a low capacity to hold nutrients. Areas with dysic Histosols, wetland soils, are also of concern for nutrient depletion because they do not receive nutrients from mineral weathering but from runoff and atmospheric deposition. Potential for nutrient depletion is high (Herrick et al., 2009). With this high potential for nutrient depletion, these areas were deemed not suitable for forest residue biomass harvest to retain as much nutrients as possible at the site.

A list of soils developed by the Wisconsin DNR was used to identify locations of the aforementioned soils of concern using soil survey maps produced by the Natural Resource Conservation Service. Soils of concern were clipped from each county soil map. All 72 county maps were then merged to identify areas where biomass harvesting was suitable and converted to raster format. Areas of suitability were assigned a value of 10 and areas not suitable assigned a value of 0.

Slope

Forest inventory that lies on slopes greater than 20% incline were eliminated due to inaccessibility using conventional harvest equipment and environmental concerns in these areas (Walsh, Perlack, Turhollow, de la Torre, Becker, and Graham, 2000). A digital elevation model was processed using the Spatial Analyst Toolbar (ESRI, 2010) to calculate slope as a percent. Areas less than or equal to 20% incline were then selected as suitable for biomass harvest. The majority of slopes greater than 20% were found to be in the southwest region of Wisconsin.

Site Location

Four locations of biomass burning facilities were identified in this study. A radius of 50 miles was applied surrounding each facility to delineate a supply shed (Figure 3).

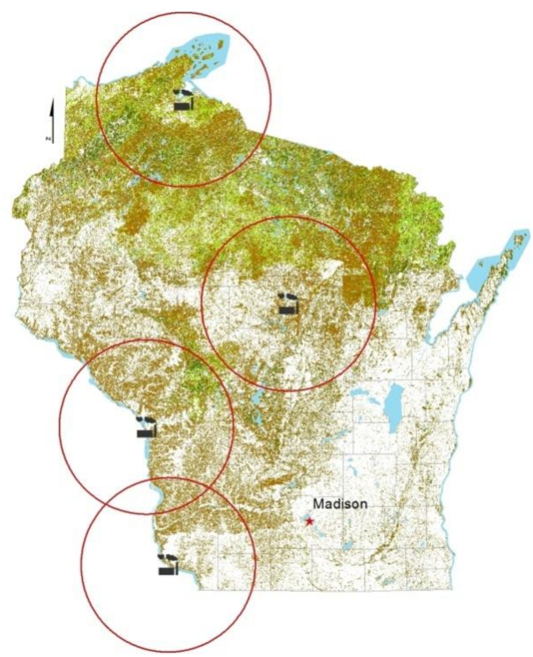

Figure 3. 50 mile radius centered on the location of electric utility plants identified in this study.

This distance is based on current economic factors and the cost of harvesting and shipping forest residue biomass by truck and trailer (Castellano et al., 2008). Shipment by watercraft or rail was not addressed in this study.

Combining Criteria

All datasets were combined using the Spatial Analyst Raster Calculator (ESRI, 2010), the result being a raster dataset showing the location where forest residue harvest was found to be suitable within the given parameters and corresponding acreage. Figure 4 depicts the general processed used to generate the final desired dataset.

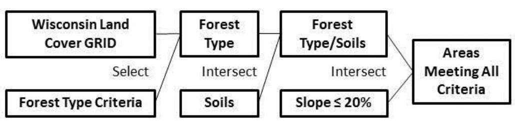

Figure 4. Generalized model showing selection criteria used to identify timberland that could produce forest residue biomass.

Analyzing the Supply Sheds

To determine the diversity index of species categories located within each supply shed the Shannon's Index (Zar, 2010) was used:

Where "*n*" is the sample size, "f_i" refers to the number of observations within each category, and "H'" is the measure of diversity. For each supply shed, 100 random samples were taken of the final forest type coverage of Aspen, Hardwoods, and Conifers. Once complete, the measure of diversity was then additionally calculated as a proportion over the maximum possible diversity of the set of data using the following:

"*k*" being the number of categories, three for the purpose of this study. The resulting quantity represents a measure of relative diversity. A numeric value closer to 1 represents a more homogenous population and a value closer to 0 represents a more heterogeneous population. Resulting "*J'*" values for each supply shed are shown in Table 3. Figure 4 displays the Rothschild supply shed in greater detail.

Table 3. J-Values by Supply Shed

Supply Shed	**J - Value**
Bayfront Plant	0.877
French Island Plant	0.598
Rothschild Plant	0.605
Stoneman Plant	0.122

Results and Discussion

The total area of forest land in Wisconsin is approximately 16 million acres. The Aspen and Balsam category accounts for 14.4% of the forest cover, while hardwoods and conifers account for 72.7% and 12.9%, respectively. Without removing areas deemed unsuitable for harvest, forest residue from aspen, hardwood, and conifer forests would produce approximately 16 million, 100 million, and 11 million oven dry tons, respectively.

Of the total acres of timberland in Wisconsin, 17.5% was removed because it did not meet the soil criteria and slope restrictions removed an additional 6.7% mostly in the southwestern region. Table 4 describes areas removed.

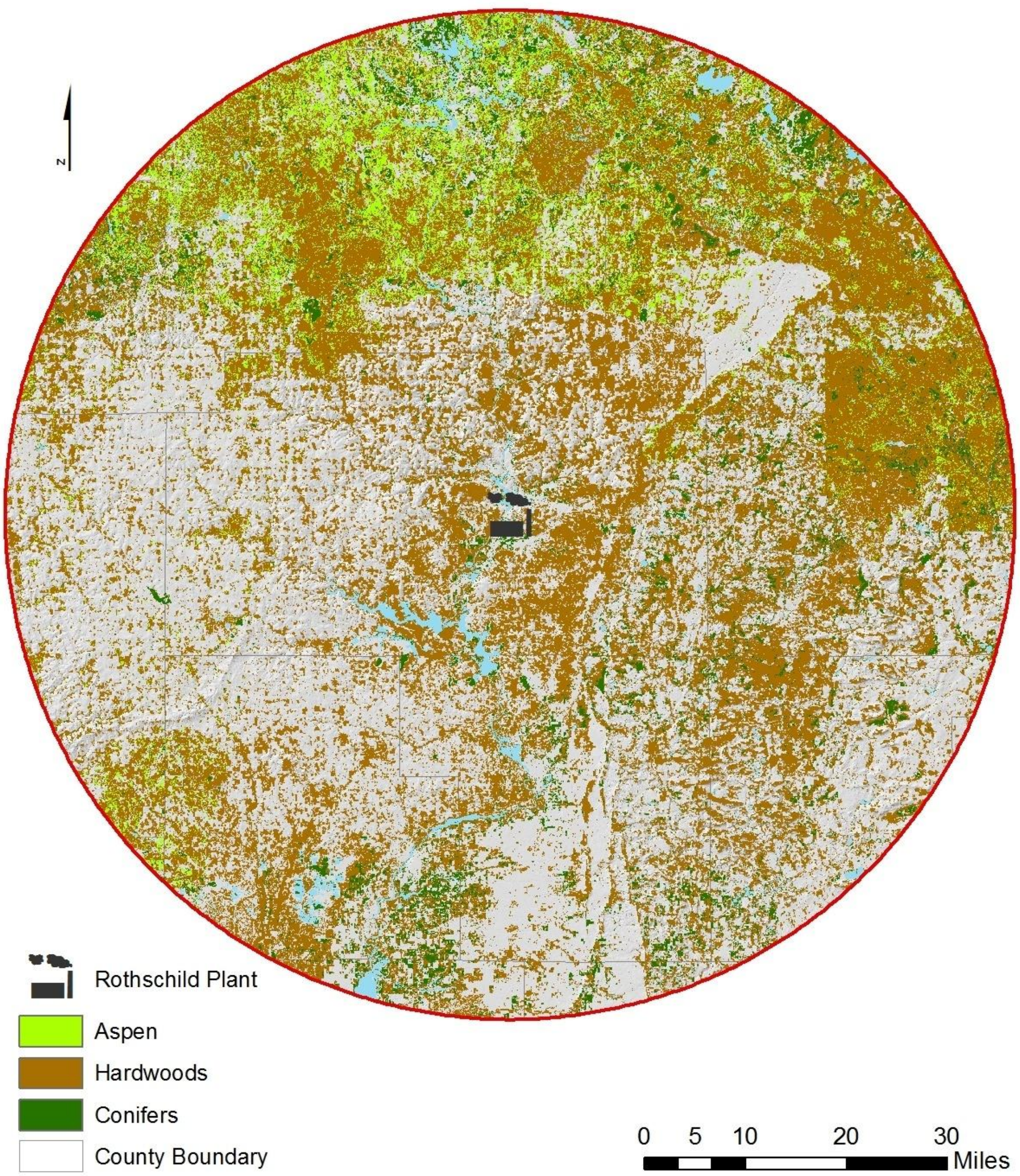

Figure 4. 50 mile radius of the Rothschild supply shed showing detail of species distribution after application of study criteria.

Totals cords of forest residue generated were also reduced by one tenth, following Wisconsin DNR guidelines for retaining nutrients in harvest areas by scattering the tops and limbs of 10% of the harvest (Herrick et al., 2009). Table 5 shows the estimated amount of forest residue biomass available by supply shed and forest type.

Considering the estimated amount of forest residue biomass and electric generation of each power plant addressed in this study, a 50 MW plant requires 52 semi truckloads a day to maintain operation (Ragland, Ostlie, and Berg, 2000). One truck load may haul 12 oven dry tons (MN DNR, 2006). Given this approximation and if under the

Table 4. Acres of timberland removed by each criteria for Wisconsin and each supply shed.

Criteria	Wisconsin	Bayfront Plant	French Island Plant	Stoneman Plant	Rothschild Plant
Total Forestland	15863082	2255160	1462010	565158	2483175
Soils	2779581	447548	259940	28209	184989
Slope (post soil criteria removal)	1065572	42529	525463	245738	11540
Land Not Meeting Criteria	3845153	490077	785403	273946	196529
Total Remaining Forestland	**12017929**	**1765082**	**676607**	**291211**	**2286645**

Table 5. Acreage of timberland by supply shed and maximum amount of oven dry tons (odt) possible from forest residue.

Forest Type	Bayfront Supply Shed		French Island Supply Shed		Stoneman Supply Shed		Rothschild Supply Shed	
	Timber Acres	Forest Residue (odt)	Timber Acres	Forest Residue (odt)	Timber Acres	Forest Residue (odt)	Timber Acres	Forest Residue (odt)
Aspen	432522	2958451	37842	342400	0	0	284815	1948141
Hardwoods	1117557	10111657	581153	5258275	285931	2587106	1807859	16357508
Conifers	215002	1161015	57610	311099	5280	28512	193970	1047438
Total	**1765082**	**14231124**	**676606**	**5911775**	**291211**	**2615618**	**2286645**	**19353088**

assumption that biomass burning electric utility plants in Wisconsin would utilize forest residue biomass exclusively to generate electricity, supplies would be depleted in 12 years, not taking into account regrowth. This of course, is not a practical solution; therefore, other sources of fuel need to be examined. While the Stoneman plant uses only wood products (Hoopman, 2010), the French Island plant burns mass from landfills in addition to wood. Sources from outside of the state could also be considered.

Supply Shed Diversity

Using values generated from the Shannon Diversity Index (Table 3), it was determined that the Bayfront plant supply shed houses the most diverse combination of forest type among the supply sheds studied. This is important for a number of reasons. Utilizing an area with a more diverse population of tree types allows for more sustainability in growth, therefore sustaining the supply of fuel. Aspen and like species, are relatively quick growing and act as a starting point for other native communities, such as the conifers that grow in the understory. Other hardwoods with a slower rate of growth, typically have several layers of woody plants, a defined canopy, sub canopy, and shrub layer. Nutrients from leaf litter and humus are mineralized quickly and become available for uptake by other plants. Conifers, quickly growing but with little understory, are naturally replaced by sun loving species such as Aspen after a disturbance (MN DNR, 2010). The Stoneman and French Island supply sheds consist of less total

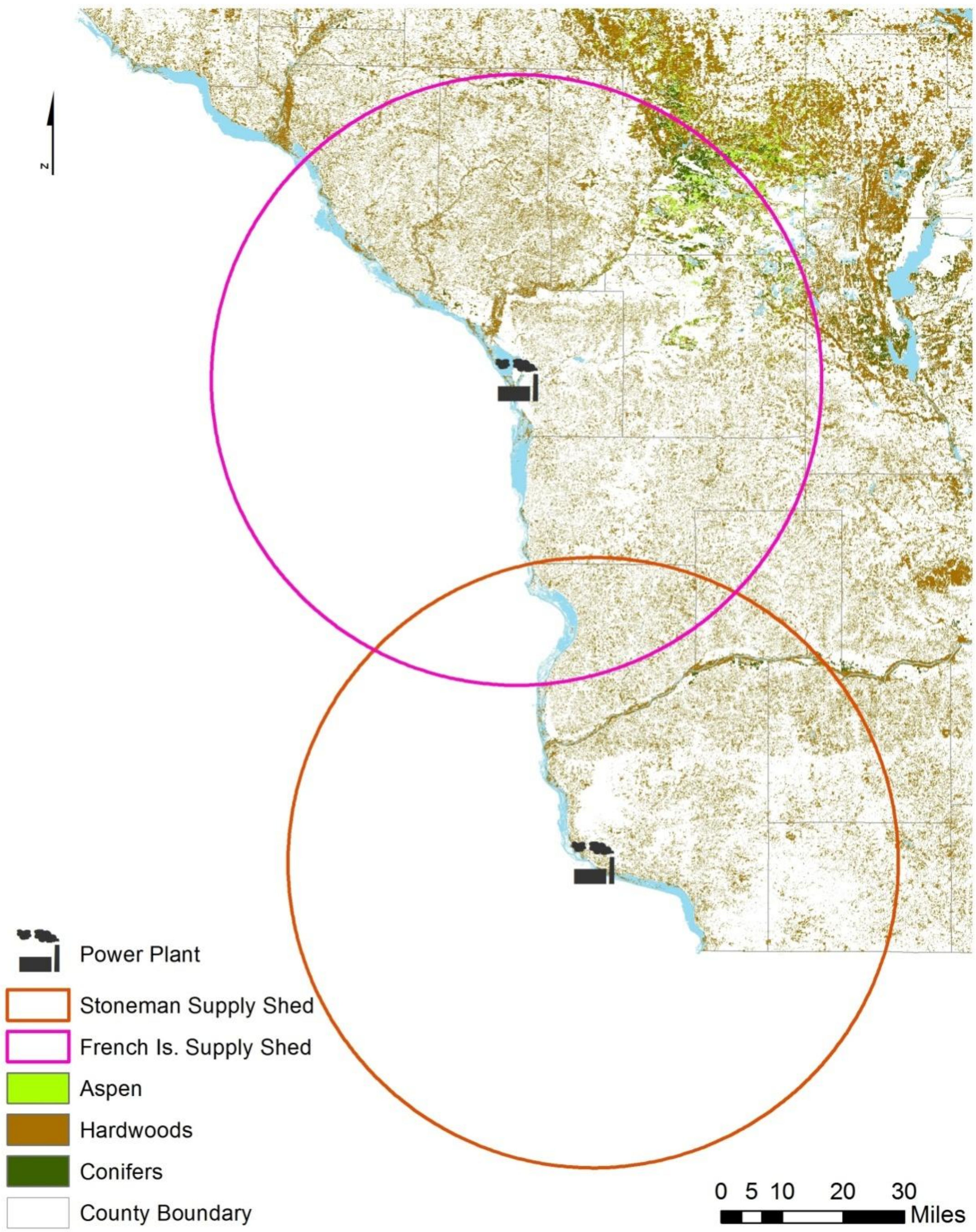

Figure 5. Detail of Stoneman and French Island supply sheds.

forested area and what is present is mostly predominated by the hardwoods category. Extra measures would need to be taken to ensure that habitat and nutrients are not depleted from the understory communities. Figure 5 shows the forest type diversity of the Stoneman and French Island supply sheds. Additionally, while much of the Bayfront and Rothschild supply shed are considered forestland, this is much less so for the Stoneman and French Island supply shed where timber is less abundant. A consideration of drawing biomass from sources other than Wisconsin could be addressed. Shipment by river barge is significantly less expensive than that by truck. Cassville's Stoneman plant could draw from sources as far south as Missouri by barge.

While it is not feasible to solely use forest residue biomass for electric utility production, it is possible to harvest a significant amount of this matter sustainably as presented in this study. The resulting data supplies a beginning source for Wisconsin landowners and specialists interested in the potential of this resource. As further advances are made, a need to identify key areas where resources can be accessed arises.

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