Final Report

Rapid Assessment of Woody Biomass Capabilities in Three Regions of the U.S. Midwest

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Executive Summary

With the development of the bioeconomy in Iowa and beyond, mounting interest is placed on the ability of biomass production systems to meet the growing demand. Woody biomass is especially compelling since trees (1) can be harvested throughout the year and kept growing until just prior to use, and are thus able to fill the gaps between harvest seasons for other types of agricultural biomass and solve the biomass storage problem, (2) offer very high energy output:input ratios, (3) stabilize soil, (4) efficiently cycle water and nutrients, (5) provide habitat for a diverse array of species, and (6) create a long-term, below-ground reservoir for carbon sequestration. Significant questions exist, however, regarding the ability of Midwestern landscapes to provide woody biomass. In an effort to answer these questions, we performed a rapid assessment of woody biomass production and supply capabilities in three regions of the U.S. Midwest—the Driftless Area, the Central Dissected Till Plain, and the area around Des Moines, IA. We used existing forest and timber inventories and conducted interviews with forest professionals to understand the accessibility of woody biomass from natural forests, the availability of and costs associated with woody biomass in the existing timber industry, and the potential for production from short-rotation woody crop plantations. Key findings include the following:

- Natural Forestlands: The Driftless Area and the Central Dissected Till Plain are 25.7% and 14.8% forested, respectively—each contains 5.4 million acres of natural forestland. The counties surrounding Des Moines are 8.4% forested, with 0.3 million acres of forestland. The net growth of woody biomass on these forests is 4.2 million dry tons/year in the Driftless Area, 5.9 million dry tons/year in the Central Dissected Till Plain, and 0.3 million dry tons/year near Des Moines. Much of this biomass is inaccessible to the bioenergy industry as it is composed of either small material that cannot be harvested in a cost-effective way or high-quality sawlogs, which are generally sold on the competitive sawtimber market in the region. An opportunity does exist, however, to capture trimmings, small-diameter, and low-quality material in conjunction with on-going intermediate stand treatments or sawtimber harvests common in the region. Costs for removing this material are estimated to range between $75-200/ac, depending on site conditions.
- Mill Residues: Based on the estimates provided by 29 sawmills, over 190,000 dry tons of mill residue was generated in the region in 2006, approximately 82% of which is available for purchase. At reported mill gate break-even prices for residue biomass ($30.81/dry ton; 28 mills reporting), a little over 58,000 dry tons would be available. At $50/dry ton, almost 102,000 dry tons of biomass would be available for sale in a biomass market. The existing, competitive market for this material is operating at an average transportation distance of 169 miles at present. Biomass is largely transported in the form of wood chips.
- Short-rotation Woody Biomass Crops: Short-rotation woody biomass crops offer important advantages that recommend them as a critical component of the overall feedstock supply system. Using currently available tree selections and plantation methods, an average of over 8 dry tons/ac/yr of lignocellulosic feedstocks can be grown on a variety of soils and topographic positions. Landowners in the region would be most likely to establish short-rotation woody crop plantations on marginal farmlands if a woody biomass market were to develop. We conservatively estimate that, on an annual basis, 1 million dry tons of biomass could be produced in the Central Dissected Till Plain, over 217,000 dry tons in the Driftless area, and over 38,000 dry tons in the Des Moines area.

- Municipal Waste Streams: A substantial woody biomass resource exists within waste streams, including over 105,000 dry tons generated annually in the Des Moines area alone. While much of this material is diffuse and difficult to collect, wood waste associated with urban centers is more concentrated in terms of production and existing waste collection services constitute a mechanism to further concentrate it. A market for compostable and mixed recyclable paper already exists in the Midwest, but most waste wood is currently landfilled and thus readily available, pending sorting and transportation costs.

In sum, the Driftless Area and the Central Dissected Till Plain possess the capacity to support a full-scale cellulosic biomass facility at present, while the Des Moines area could support a pilot to moderate-scale biorefinery. On an annual basis, the Driftless Area produces 11.5 times the material required by a facility using one-half million dry tons of woody biomass per year. Although allocated over a larger area, the Central Dissected Till Plain produces 14.8 times the required material. The Des Moines area produces 0.4 million dry tons of woody biomass per year. The key issues to overcome in establishing a wood-using biorefinery in the region are inefficiencies in accessing and transporting the diffusely distributed raw material. In time, plantations of short-rotation woody crops could do much to overcome these hurdles.

Introduction

With the development of the bioeconomy in Iowa and beyond, mounting interest is placed on the ability of biomass production systems to meet the growing demand. While it is expected that corn grain will meet much of the initial demand, cellulosic biomass feedstocks provide a longer term solution. Perennial cellulosic feedstocks pose numerous advantages including a higher energy output:input ratios, less negative impacts on soil and water resources, and ability to grow across a wider range of climate and landscape conditions (Tilman et al. 2006). Cellulosic biomass derived from wood is especially compelling since trees can be harvested throughout the year and kept growing until just prior to use. Trees are thus able to fill the gaps between harvest seasons for other types of agricultural biomass and solve the biomass storage problem. Trees further offer very high energy output:input ratios of 55:1 (Keoleian and Volk 2005).

Significant questions exist, however, regarding the ability of the Iowa landscape to provide woody biomass. How much woody biomass is out there? Where is it? How much of it is accessible, for logistic, social, or environmental reasons? Is there an existing infrastructure that can harvest, collect, and transport woody biomass? Is there a willingness to invest in woody biomass plantations? What can be done to support woody biomass production?

In an effort to answer these questions, we assessed the woody biomass production and supply capabilities within three regions in and around Iowa. Two of the regions we assessed, the Midwest Driftless Area and the Central Dissected Till Plain, possess a substantial forest resource. The Midwest Driftless Area (or Paleozoic Plateau) spans 20.9 million acres and includes eight counties in northeast Iowa, and surrounding counties in southeast Minnesota, southwest Wisconsin, and northwest Illinois (Fig. 1). While rowcrops dominate the bluff tops and valleys in this topographically dissected landscape, forests cover the hillsides, comprising approximately 26% of the region. The eastern portion of the Central Dissected Till Plains includes 37 counties in Iowa, plus adjacent Missouri and western Illinois, and is 36.2 million acres in extent (Fig. 1). Forests comprise 15% of this flat to rolling landscape at present, but many areas are reverting back to forest since soils are only marginal for growing rowcrops. Both areas possess an active sawlog and veneer timber industry.

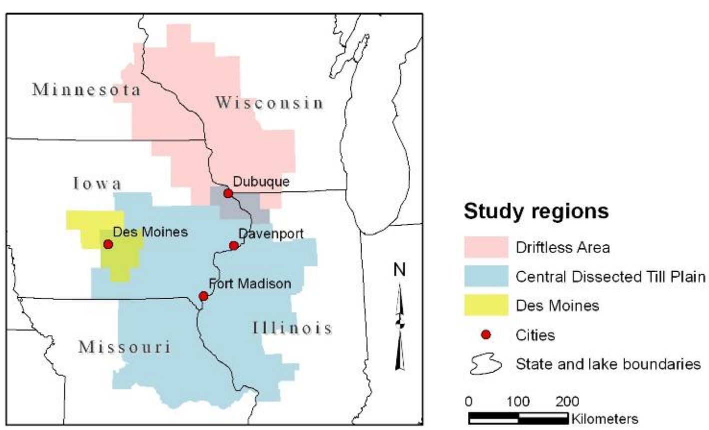

Fig. 1. Study regions

The third area is composed of nine counties surrounding Des Moines, Iowa (Fig. 1). While this 3.3 million acre area is not heavily forested, it does provide an opportunity to take advantage of a significant source of woody biomass in the municipal waste stream associated with Des Moines. Our analysis of the Des Moines area is furthermore geared toward the ability of this region to support a pilot biorefinery, rather than a commercial facility. Alternatively, it might be possible to site a moderate-scale facility south of Des Moines and be within an economical haul distance of both municipal wood wastes and the heavily forested areas of southern Iowa and northern Missouri.

For these three regions, we assess the availability of woody biomass within natural forests and the existing timber industry. We further assess the woody biomass generated as waste in urban forestry projects and present in the municipal waste stream from four urban centers in the regions—Davenport, Des Moines, Dubuque, and Ft. Madison. As examples, we assess ability of these four urban centers to support a local biorefinery, because of the availability of the urban waste wood, existing transportation networks, and readily available energy markets. Also, Davenport, Dubuque, and Fort Madison are located along the Mississippi River (Fig. 1), offering potential comparative advantages in terms of transportation costs associated with woody biomass delivered to and fuels shipped from a biorefinery. Fort Madison also poses a comparative advantage in terms of an existing commercial infrastructure (e.g., logging equipment for small diameter stem harvests, transportation networks), which supported a pulp mill until 2005. It is noteworthy that this mill is no longer in business due to shifts in the global papermaking industry, not because of a lack of raw material or supportive infrastructure. The mill had been operated by International Paper with a product capacity of 77,000 tons/yr which equates approximately to 154,000 tons of wood supplied (CPBIS 2007).

Much of the information we assessed was derived from existing U.S. Forest Service inventories of forest conditions and the timber industry (USFS 2007a, USFS 2007b). In cases where the available data was not expressed as dry weights (i.e., sawtimber volume, net growth, removals), the standard measure used by the bioenergy industry, we converted available cubic feet volumes using conversion estimates from the published literature (Bower et al. 2003). We further conducted ad hoc and structured interviews with public and private foresters from the region to understand the accessibility of woody biomass from natural forests and the potential for short-rotation woody biomass production. To gain more precise understanding of the availability and costs associated with woody biomass in the existing timber industry, we also contacted and conducted interviews with many of the existing wood processing facilities in these regions. We attempted to gather information on potential wood biomass available from urban forestry tree maintenance operations and storm damage, but were unable to find regional or state-based sources of such data. Estimates of woody biomass availability within other municipal waste streams is derived from ad hoc interviews with professionals working in this field and a waste characterization study conducted in Iowa in 2005 (Iowa DNR 2006).

Biomass in Natural Forests: Amount and Composition

The latest USDA Forest Service estimate for the state indicates 5.4 million acres of timberland in each of the Driftless Area and Central Dissected Till Plain regions, up from 5.2 and 4.5 respectively around 1990 (Table 1). The amount of timberland[1] near Des Moines increased from 0.2 to 0.3 million acres between 1990 and 2007, an increase of 3.2% (Table 1). While conversion of natural forestlands to agricultural land was characteristic of the post-WWII era in the Midwest, regional-to-global economic forces have caused a reversal of forestland conversion, which is shown by these data. Future expansion of urban areas and new land clearing for agriculture may reduce these recent gains in forest land.

[1] Timberland is a subset of forestland that is "producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation" (Smith et al. 2003); most forestland in these regions is timberland.

Table 1. Changes in timberland area (USFS 2007a).

Region	Land Area	Timberland Area ~1990*		Timberland Area in 2005	
	million ac	million ac	%	million ac	%
Driftless Area	20.9	5.2	24.8	5.4	25.7
Central Dissected Till Plain	36.2	4.5	12.4	5.4	14.8
Des Moines	3.3	0.2	5.2	0.3	8.4

*Survey year variable by state: IA = 1990; IL = 1985; MO = 1989; MN = 1990; WI = 1996.

Eighty-seven percent of these timberlands are owned by non-industrial private forest, or family, ownership (USFS 2007a). States and counties/municipalities make up the majority of the remaining ownership, with approximately 5% of the land base each (USFS 2007a). Historically, the private forests were associated with farms; however, this demographic has shifted in recent decades. Private ownership here as elsewhere in the U.S. is increasingly dominated by people who do not make their livelihood through agriculture and are often absentee (Butler and Leatherberry 2004). Although we lack specific numbers, discussions with practicing foresters in the region suggest that the average size of forest ownership in these regions is declining, as elsewhere in the U.S. Nationally, average private forest ownerships measure 38 ac (Butler and Leatherberry 2004).

The overall amount of woody biomass is variable by location and by species within the forests of these regions. Counties in the Wisconsin portion of the Driftless Area and the Missouri portion of the Central Dissected Till Plain possess the largest woody biomass resource (Fig. 2); however, substantial resources also exist within Allamakee and Clayton counties, Iowa. Although the regions support high tree diversity, most of the biomass is found within a few species, including species of maple (black, red, silver, and sugar), shagbark hickory, oak (white, bur, northern red, and black), and American elm (Table 2). Silver maple comprises much of the biomass along the Mississippi River.

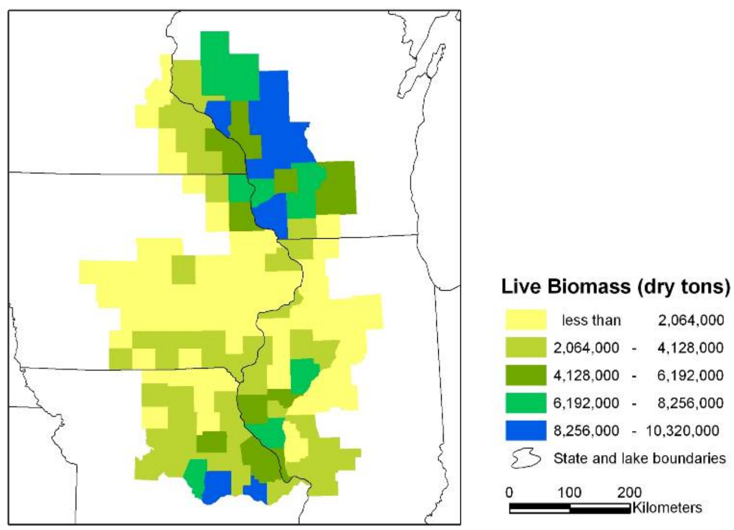

Fig. 2. Total live biomass by county

A large portion of the existing woody biomass resource would not be available for bioenergy production, however, because of a vibrant sawlog industry already existing in these regions. The sawlog industry would out-compete most other timber sectors on stumpage prices for sawlogs (see *Stumpage Prices* section below). Therefore, we also computed the level of the non-sawlog woody biomass resource. Although the spatial pattern of availability is similar to that of total live woody biomass, non-sawlog material comprises a much greater proportion of the biomass in the northern portion of the Central Dissected Till Plain (Fig. 3).

Non-sawlog biomass is also highly variable by species (Table 2). Species in which non-sawlog material generally comprises >75% of the total biomass across regions include boxelder, red maple, paper birch, bitternut hickory, honey locust, butternut, osage-orange, red mulberry, Eastern hop hornbeam, black locust, black willow, American elm, and 'other hardwoods' (e.g., American hornbeam, ailanthus, pawpaw, sassafras, rock elm, etc. combined). Species in which non-sawlog material comprises 55-75% of the total biomass across regions include Eastern red cedar, jack pine, red pine, hickory species (bitternut, shagbark, shellbark, and mockernut), hackberry, black ash, quaking aspen, black cherry, chinkapin oak, post oak, and slippery elm. Several species, including ashes, elms, and butternut, are threatened by insect or disease problems that might be reduced by carefully applied sanitation harvests.

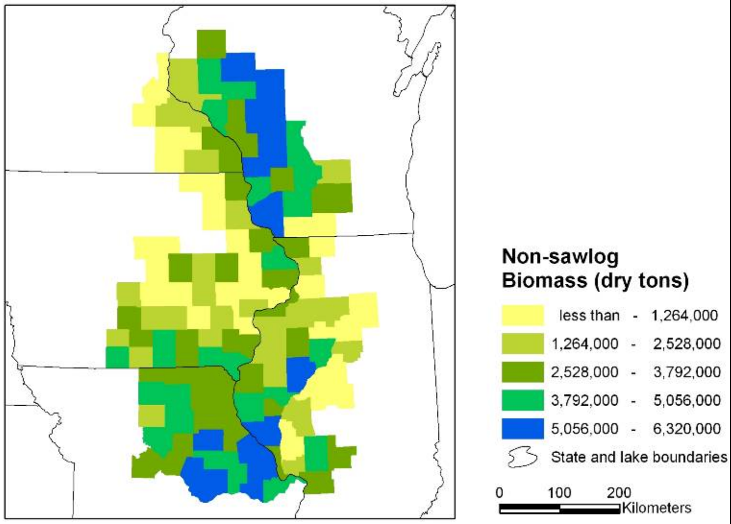

Fig. 3. Total non-sawlog live biomass by county

Table 2. Total live biomass and total non-sawlog biomass in dry tons for three regions (USFS 2007a; see Appendix A for scientific names of trees).

	Total live biomass			Total non-sawlog biomass		
Tree Species	Driftless Area	Central Dissected Till Plain	Des Moines	Driftless Area	Central Dissected Till Plain	Des Moines
Eastern redcedar	1,295,890	2,836,523	130,250	764,136	1,717,498	104,398
Jack pine	1,885,385	19,070	0	1,063,659	19,070	0
Red pine	4,184,122	233,931	0	1,859,782	168,561	0
Eastern white pine	6,085,323	932,772	0	1,813,091	147,185	0
Boxelder	5,629,167	3,083,272	386,455	4,977,910	2,752,142	386,455
Black maple	1,726,919	967,393	65,170	872,075	524,463	65,170
Red maple	11,962,386	32,461	0	8,949,671	32,461	0
Silver maple	7,573,974	17,587,281	673,758	3,173,287	6,473,704	183,414
Sugar maple	10,207,709	7,201,285	0	5,660,923	3,651,447	0
River birch	481,840	838,640	0	272,203	443,675	0
Paper birch	5,403,235	17,694	0	4,421,444	17,694	0
Bitternut hickory	3,703,324	5,355,327	378,651	2,765,729	3,089,212	279,306
Pignut hickory	0	1,275,139	0	0	537,581	0
Shellbark hickory	0	743,176	0	0	426,683	0
Shagbark hickory	7,156,903	16,333,974	439,396	4,480,374	8,535,444	318,283
Black hickory	0	719,730	0	0	345,318	0
Mockernut hickory	0	1,711,029	0	0	1,187,288	0
Hackberry	1,611,666	8,020,975	684,028	1,040,357	4,061,976	387,041
White ash	3,437,246	4,784,242	183,832	1,916,758	2,275,145	90,173

Table 2. Continued.

Tree Species	Total live biomass			Total non-sawlog biomass		
	Driftless Area	Central Dissected Till Plain	Des Moines	Driftless Area	Central Dissected Till Plain	Des Moines
Black ash	1,456,742	67,984	44,083	948,821	18,840	18,265
Green ash	3,040,663	3,344,157	119,594	1,837,949	1,654,584	43,485
Honeylocust	112,912	5,790,647	593,359	91,239	3,141,389	482,121
Butternut	515,430	24,122	16,364	423,770	9,403	16,364
Black walnut	5,256,580	8,950,747	599,828	2,123,079	3,809,599	216,203
Osage-orange	0	3,240,920	43,620	0	3,240,920	43,620
Red mulberry	181,862	1,592,732	267,403	181,862	1,433,451	256,332
Eastern hophornbeam	2,418,923	1,043,126	87,391	2,418,923	1,043,126	87,391
Sycamore	0	3,398,542	6,949	0	812,126	6,949
Eastern cottonwood	2,212,071	3,792,734	538,034	776,799	675,182	69,366
Bigtooth aspen	5,252,038	130,868	0	2,742,422	54,961	0
Quaking aspen	5,628,561	48,955	0	4,059,305	25,240	0
Black cherry	6,031,055	3,948,571	230,462	4,239,617	2,424,558	182,224
White oak	23,265,298	38,739,600	1,426,372	11,321,431	13,898,782	506,916
Swamp white oak	713,200	3,047,474	0	347,411	1,060,528	0
Northern pin oak	7,302,752	432,203	0	0	152,005	0
Shingle oak	0	7,758,220	54,922	0	3,697,734	0
Bur oak	13,198,873	9,399,144	1,648,545	0	5,299,904	0
Chinkapin oak	143,466	2,810,477	52,728	84,814	1,620,133	52,728
Pin oak	227,567	3,799,228	243,343	16,603	1,084,337	27,954
Northern red oak	30,369,552	15,535,177	1,325,039	12,230,154	4,150,468	336,718
Post oak	0	3,231,463	0	0	1,932,423	0
Black oak	10,926,389	14,308,129	88,788	6,283,207	5,205,189	50,891
Black locust	733,708	2,313,150	71,925	611,728	1,445,410	57,811
Black willow	406,174	1,313,114	230,298	143,604	888,715	180,474
American basswood	8,224,494	2,653,382	440,644	4,292,598	942,701	105,222
American elm	10,191,600	10,255,743	941,068	7,644,647	7,417,195	701,796
Slippery elm	3,506,319	3,760,343	477,324	2,358,427	2,307,344	350,311
Other softwoods	970,909	59,275	2,264	510,244	30,693	2,264
Other hardwoods	1,379,303	4,379,193	41,600	1,206,231	2,289,954	41,600
Other unknown	158	1,236	0	0	1,236	0
Total	216,011,688	231,864,570	12,533,487	110,926,287	108,174,677	5,651,245

Total live biomass and total non-sawlog biomass dramatically increases with haul distance of the four urban centers we target (Figure 4). Davenport, Dubuque, and Fort Madison all possess similar amounts of woody biomass within a given distance, perhaps due to their location along the Mississippi River, with its substantial forest resource.

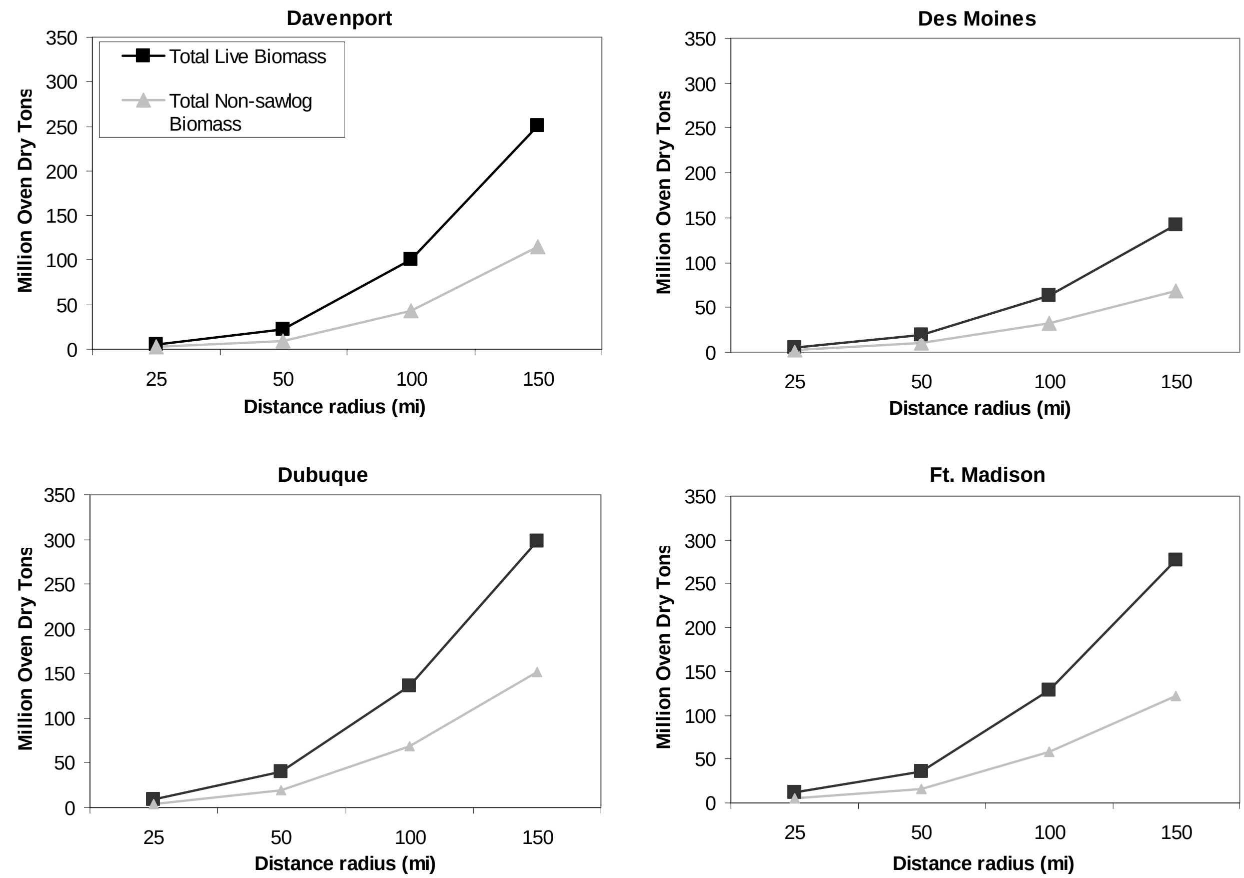

Fig. 4. Woody biomass availability within four haul distances of urban centers

Much of the biomass incorporated in the total live biomass metric, however, has accumulated over some time. ***Net growth*** indicates the accumulation of woody biomass on an annual basis, and provides information on what could be sustainably harvested within a given area over time. Net growth varies from a low of 71,000 and a high of 224,000 dry tons (US short) per year within 25 miles of Davenport and Ft. Madison, respectively (Fig. 5). At present, natural forests within 50 miles distance of both Dubuque and Ft. Madison produce well over a half million dry tons of woody biomass annually (Fig. 5).

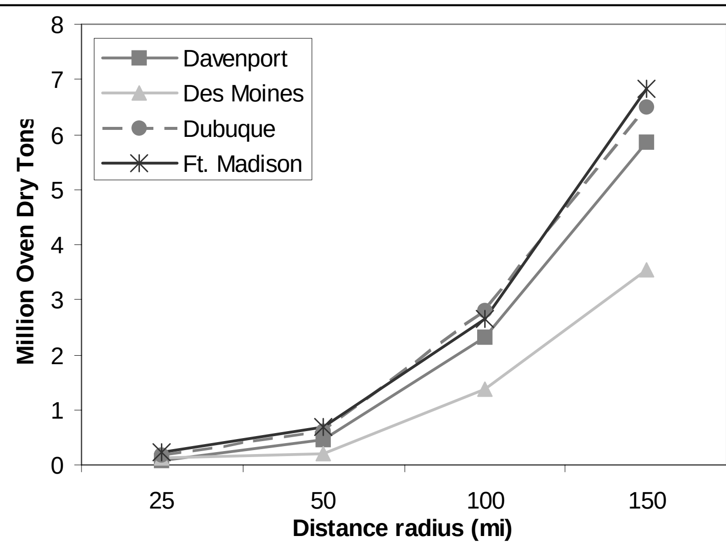

Fig. 5. Annual net growth within four haul distances of urban centers

Again, not all of this material would be available for bioenergy production. Much of the biomass accumulated in species with high sawtimber value, largely oaks and maples (Table 3), and only a small, unknown percentage of the biomass of these quality hardwoods would be available from stand thinnings. This is especially the case near Dubuque and less of an issue near Ft. Madison. Non-sawtimber species that accumulate a high amount of biomass annually include red pine, white pine, red maple, quaking aspen, American elm, slippery elm in the Driftless Area; hackberry, honeylocust, Eastern cottonwood, sycamore, shingle oak, black locust, and American elm in the Central Dissected Till Plain; and hackberry, honeylocust, Eastern cottonwood, and American elm near Des Moines (Table 3). The proportion of net growth attributable to honeylocust in the Des Moines area is especially high at 25%.

Table 3. Annual net growth in dry tons for three regions (USFS 2007a; see Appendix A for scientific names of trees).

Tree Species	Driftless Area	Central Dissected Till Plain	Des Moines
Eastern redcedar	30,040	70,937	2,504
Jack pine	40,357	559	0
Red pine	287,310	8,251	0
Eastern white pine	135,044	7,491	0
Boxelder	40,290	5,678	6,757
Black maple	41,270	38,372	0
Red maple	291,878	-11,973	0
Silver maple	108,454	375,378	15,172
Sugar maple	153,038	203,840	0
River birch	43,413	42,852	0
Paper birch	-33,092	58	0
Bitternut hickory	68,578	101,849	1,323
Pignut hickory	0	33,094	0
Shellbark hickory	0	4,791	0
Shagbark hickory	158,589	403,078	19,141
Black hickory	0	3,605	0
Mockernut hickory	0	-29,151	0
Hackberry	57,932	289,904	16,652
White ash	57,566	186,328	1,531
Black ash	36,047	80	0
Green ash	119,316	161,296	7,982
Honeylocust	7,727	306,821	68,802
Butternut	14,494	353	0
Black walnut	162,855	331,489	13,396
Red mulberry	1,943	11,857	0
Sycamore	0	140,530	2,916
Eastern cottonwood	82,925	198,808	17,106
Bigtooth aspen	-3,704	1,388	0
Quaking aspen	88,269	3,443	0
Black cherry	130,372	189,663	6,766
White oak	268,260	568,580	23,463
Swamp white oak	19,303	87,426	0
Northern pin oak	160,994	1,600	0
Shingle oak	0	264,311	3,282
Bur oak	225,086	375,013	33,370
Chinkapin oak	1,019	17,526	0
Pin oak	0	106,903	10,522

Table 3. Continued.

Tree Species	Driftless Area	Central Dissected Till Plain	Des Moines
Northern red oak	725,161	458,764	20,978
Post oak	0	39,097	0
Black oak	98,293	181,079	2,678
Black locust	9,904	182,552	2,567
Black willow	10,232	9,974	-40,041
American basswood	196,948	94,114	10,753
American elm	253,699	191,613	27,675
Slippery elm	111,047	51,820	2,460
Other softwoods	33,733	-2,199	0
Other hardwoods	10,385	146,619	0
Total	4,244,976	5,855,460	277,753

Net growth also provides an indication of the health of the resource. For example, while the Driftless Area possesses a substantial amount of biomass in paper birch and bigtooth aspen (Table 2), annual mortality exceeds growth at present (Table 3), suggesting that much of it is in decline.

Accessing Biomass from Natural Forests

In addition to distance to market center, accessing woody biomass from natural forests depends on land owners' willingness to sell and logistical constraints posed by the environment (i.e., steep topography, wet soils). Our ad hoc and structured interviews with professional foresters in the region suggest that a good energy market for biomass would likely encourage many landowners to do more timber stand improvement thinnings in their stands, remove excess wood wastes following sawlog harvests, and perhaps establish new tree plantations specifically to supply energy wood.

Foresters expect, however, that managing natural forests specifically for biomass is not feasible. They see biomass harvesting as a secondary goal, to be achieved in association with timber stand improvement cuts (e.g., thinnings, crop tree release) or other intermediate treatments such as invasive species eradication. Even in these cases, the acquisition of woody biomass will be expensive given the small spatial extent over which these practices are carried out in the region. Large sales in the region are considered 5-6 ac for a clearcut and 20-30 ac for selective harvest; sales of this size only occur on about 10% of landholdings. The foresters estimated biomass removal costs at $75-200/ac, which is typical of timber stand improvement (TSI) treatments at present. Costs vary depending on the mix of sizes present on site.

At present, most timber improvement activities involve girdling trees and not removing them, for speed and to keep the cost down. In Iowa, many weed tree/crop tree management areas have too few stems and are only 10 acres in size. Most material and almost all tree tops are left on site, although some might be removed by a landowner or logger for firewood purposes. If chippers were readily available, "in the woods" chipping would lower the cost of woody biomass extraction from natural forests. Whole tree utilization is generally desirable, but most operators do not want to make chips from tops or low density stands.

The foresters also saw biomass harvests from bottomlands as more feasible than uplands, due to the higher density and lower quality of the bottomland material. Of upland forests, maple-basswood may be more amenable than oak forests. Foresters would be eager to remover elm, which is a common and undesirable competitor in maple-basswood forests. Biomass harvesting from upland oak forests was seen as least feasible as foresters like to keep the slash on site to protect regenerating seedlings from deer herbivory.

Landowner Willingness to Accept—The foresters we interviewed expect that a moderate percentage (20-33%) of regional landowners would be willing to engage in biomass harvests. In South Central Iowa, the majority of land owners who are currently managing for timber (about 20-25% of forest landowners) would likely be amenable to biomass collection. In SE Iowa, 25-33% would be readily agreeable. Such a market would likely spur additional and new TSI. In NE Iowa, if biomass collection meant higher timber prices about 30% of the landowners would be willing to harvest. All forest management plans written by these foresters recommend harvesting practices (e.g., TSI, crop tree release, weed tree removal, natural regeneration prescriptions), though the long-term objectives may vary.

Foresters perceive a tipping point in relation to harvesting biomass from natural forests: at what biomass extraction level can landowners cut trees and still achieve their non-market goals? Foresters also expect, however, that at least 25-40% of landowners as having strong attitudes against allowing large equipment on their land. In many cases, the land is somewhat fragile (e.g., steep slopes, large gullies with active erosion) and cannot handle large equipment.

Readily Accessible Biomass—Our interviews with foresters suggest that a substantial amount of woody biomass may be available in the short term from two sources. First, plantations of white, red, and jack pine established in the 1940s and 50s are generally not well adapted to their sites and have largely plateaued in productivity. Many land owners (state and private) are looking to heavily thin these white pine stands and/or liquidate red and jack pine stands and establish a different forest type. Although these plantations comprise only a small portion of woody biomass on the Central Dissected Till Plain and around Des Moines, they make up 2.8% of the woody biomass within the Driftless Area.

Secondly, 1993 floods along the Mississippi and other rivers converted many mature lowland savannas and bottomland hardwood forests to dense stands of primarily silver maple and box elder. There may be some areas where landowners would be interested in whole scale conversion (e.g., clearcutting) and simply starting over again. The Army Corps of Engineers, which owns and manages much of the land along the Mississippi corridor, is interested in restoring these areas to their native ecosystem types. A market outlet for the woody biomass would help pay for restoration costs. Harvesting in these systems can be difficult, however, due to their lowland character. But under the right weather conditions, these areas can be amenable to large, mechanized equipment (e.g. drag skidder). Across regions, 17.6 million dry tons of woody biomass is comprised of non-sawlog material of silver maple and box elder (Table 2).

Ecological Constraints to Harvesting Woody Biomass—Woody biomass poses many benefits as a biomass crop, and can contribute to a more sustainable global energy budget when grown and harvested in an environmentally-sensitive manner. Site-level environmental concerns are not negligible, however, and include maintenance of soil productivity, water quality, and habitat for biodiversity. To address these environmental concerns, the Minnesota Forest Resources Council developed guidelines for harvesting woody biomass from natural forests (MFRC 2007). A brief summary of these guidelines follows; see MFRC (2007) for specifics:

- *To maintain soil productivity*, (a) limit disturbance of the forest floor, including understory plants, litter layer, and tree root systems, (b) roads, landings, and stockpiles should occupy no more than 1-3% of a harvest site and be regenerated after use, and (c) avoid additional biomass harvest from erosion-prone sites and sites with thin, sandy, or organic soils. In the case of silvicultural prescriptions calling for disturbance of the forest floor (e.g., methods for regenerating oak), removal, or piling of small material should be avoided.
- *To maintain water quality*, (a) leave significant amounts of vegetation cover on all harvest sites and (b) avoid biomass harvesting within riparian areas and within 25 feet of a dry wash banks.
- *To maintain habitat for biodiversity*, (a) avoid biomass harvest in sensitive native plant communities or at/near known locations of Endangered or Threatened Species, (b) retain rooted and uprooted stumps, (c) retain snags and downed dead woody debris, (d) retain and scatter tops and branches from 20% of harvested trees, (e) avoid removing tops and limbs resulting from incidental breakage, and (f) retain approximately one-third of fine woody debris on a site (i.e., intentionally retain tops and limbs from one out of every five trees harvested, plus retain 10 –15% of material created by incidental breakage during skidding).

The foresters we interviewed suggest leaving 33-50% of tree residues on site to maintain soil and habitat quality. It may be beneficial to leave more than this if the potential for erosion is high or if natural regeneration is likely to be negatively impacted by deer herbivory—this is especially a problem with oak regeneration in the region. It is expected, however, that the majority of nutrients are returned to soils through leaf fall and, since ample dead wood exists in these forests for habitat, leaving coarse woody debris on harvested sites is not a major concern at present.

Biomass in the Existing Timber Industry

Surveys of the existing timber industry and interviews with professional foresters suggest that only a small portion of the woody resource in these regions is being accessed at present. Based on U.S. Forest Timber Product Output data[2] (USFS 2007b), total harvesting activity currently measures a small portion of the total wood biomass resource available and has been fairly stable over time. Current harvests are somewhat higher in the Driftless Area, due to changes in the industry that have allowed the use of smaller diameter material, and slightly lower in the Central Dissected Till Plain (Fig. 6), due to the loss of a pulp mill in the region. The Driftless Area furthermore shows the highest level of harvesting activity of the three regions, with 1.7% of the total live biomass is harvested annually (Fig. 7); in other words, these forests are on a 59 year rotation at present. Harvesting levels are lower in the Central Dissected Till Plain (0.9%

[2]To generate harvest data and logging residues, the U.S. Forest Service visits a cross-section of logging operations and characterizes sites logged, trees cut, products taken, and residues left behind. Mill residues are determined by canvassing wood-using mills.

harvested annually or 111 year rotation) and near Des Moines (0.3% harvested annually or 333 year rotation).

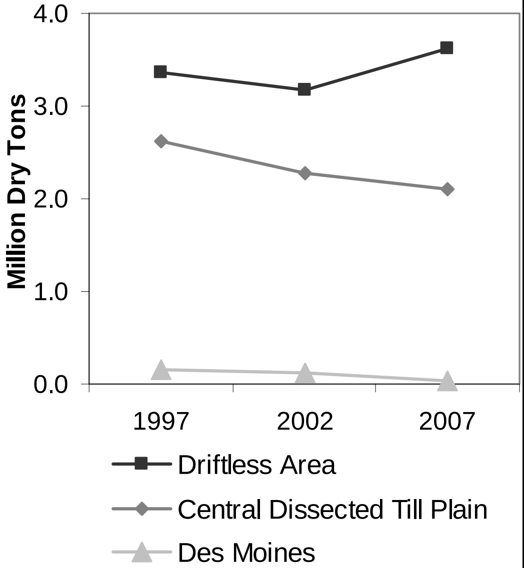

Fig. 6. Total removals over time

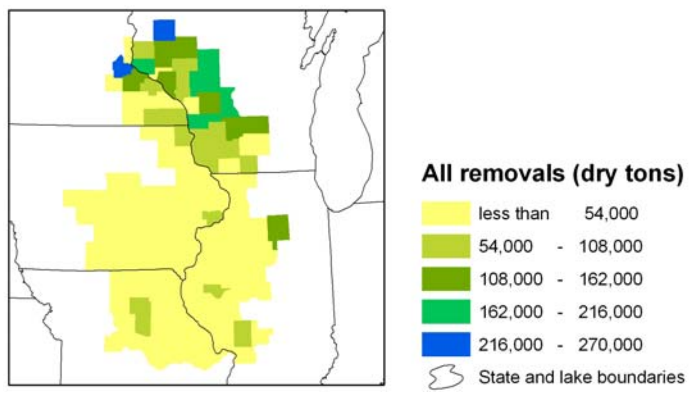

Fig. 7. Total removals by county

Of the overall biomass harvested annually, the proportion currently transferred into a measurable product is variable by region. Forty-seven percent of the biomass harvested annually in the Driftless Area is transferred to product; high-value veneer and sawlogs account for 45% of the total removals[3] here, while the remaining harvested material is either composed of logging or mill residues[4], or low-value products including pulpwood, composites, posts, poles, pilings, and fuelwood. This is less the case in the Central Dissected Till Plains, where residuals and low-value products make up 66% of total harvests, and dramatically the case in the Southern Des Moines Lobe, where residuals and low-value products comprise 94% of all harvests (Table 4). Whereas it is unlikely that the bioenergy industry could compete with the high prices that sawlogs already receive, residuals and low-value products may offer economically viable opportunities (see *Stumpage Prices* section below). In terms of species mix, much of the red pine, aspen, cottonwood, elm, and other softwoods and hardwoods comprise the majority of the volume of low-value timber products and could most readily be captured by the bioenergy market. Harvests in the Driftless Area currently capture the most volume within these species (Table 5).

[3]Annual removals are "the net volume of growing stock trees removed from the inventory during a specified year by harvesting, cultural operations such as timber stand improvement, or land clearing" (Smith et al. 2003). The growing stock is comprised of "live trees of commercial species meeting specified standards of quality or vigor. Cull trees are excluded. When associated with volume, includes only trees 5.0 inches d.b.h. and larger."

[4]According to Smith et al. (2003), mill residues include "bark and woody materials that are generated in primary wood-using mills when roundwood products are converted to other products. Examples are slabs, edgings, trimmings, miscuts, sawdust, shavings, veneer cores and clippings, and pulp screenings. Includes bark residues and wood residues (both coarse and fine materials) but excludes logging residues.

*Table 4.*Timber harvest, product, and residue metrics for three regions in dry tons (USFS 2007b).

Region	Total Harvests	Total Logging Residues	Total Mill Product	Total Low-value Mill Product	Total Mill Residues
Driftless Area	3,627,694	644,287	1,707,180	931,331	424,001
Central Dissected Till Plain	2,104,217	549,188	1,186,754	486,736	347,635
Des Moines	42,900	3,883	39,012	36,357	n/a*

*Mill residue data are not available for the Des Moines region because too few mills reported

Table 5. Total removals in dry tons for three regions by species group (USFS 2007b).

Species	Driftless Area	Central Dissected Till Plain	Des Moines
Red pine	124,969	223	0
Ash	74,311	107,873	1,200
Aspen	346,392	313	0
Basswood	106,974	7,535	584
Cottonwood	223,729	105,246	629
Elm	156,439	75,008	1,543
Hickory	52,970	102,133	2,978
Maple	448,887	243,287	9,138
Red oak	925,998	569,976	8,726
White oak	605,379	735,444	14,952
Black walnut	65,435	116,430	1,136
Other softwoods*	169,646	6,976	54
Other hardwoods#	168,151	173,193	3,693
Total	3,469,282	2,243,637	44,632

*Combination of softwood conifer species with <100,000 dry tons in individual removals.
#Combination of hardwood broadleaf species with <100,000 dry tons in individual removals.

A substantial portion of the harvested biomass in the Driftless Area (17.8%) and the Central Dissected Till Plain (26.1%) remains on site as logging residue[5], at cost to the owner or logger, because markets for the material are currently small to non-existent (Fig. 8). Interviews with professional foresters suggest that the accessibility of this material is questionable, due to the high costs associated with handling this small diameter material. Yet, as harvests have increased over time (Fig. 6), the overall biomass that comprises logging residues has declined (Fig. 9), suggesting changes that allow the collection and transport of a wider array of woody material are already occurring in the regional industry.

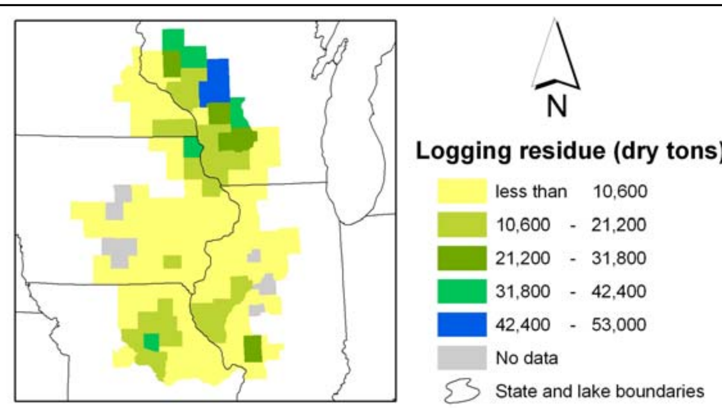

Fig. 8. Total logging residues by county

[5]Logging residues are "the unused portions of growing-stock and non-growing-stock trees cut or killed by logging and left in the woods" (Smith et al. 2003).

Given that a low volume of woody material is captured from fairly large areas with this uneven-age silvicultural system, the collection of small diameter material is unlikely to be profitable. Furthermore, residual material from logging performs important ecological functions in protecting regeneration from deer browsing, returning carbon to the soil, and slowing erosion on steep slopes.

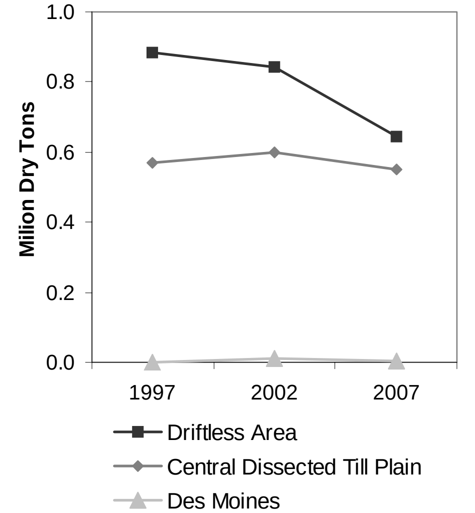

Fig. 9. Total logging residues over time

According to state natural resource agencies or cooperative extension services, sawtimber and veneer mills are scattered across the region; yet, many of these mills are small and are prone to market volatility. The spatial pattern in mill residues, hence, coincides with the location of the larger, more stable sawtimber mills in the region (Fig. 10). The overall production of mill residues has remained stable over time (Fig. 11), with slight declines associated with the development and use of more efficient machinery within the industry.

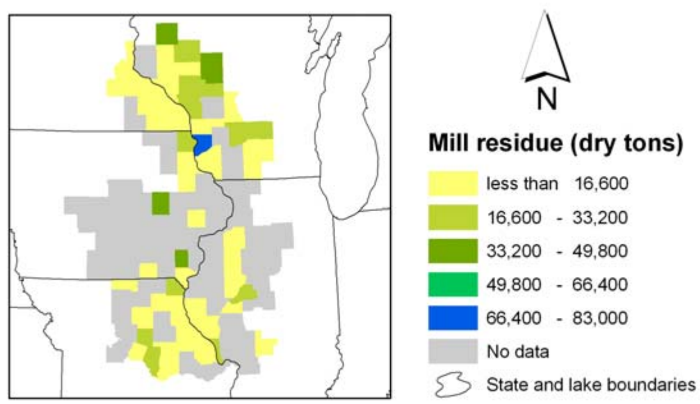

Fig. 10. Total mill residues by county

Interviews with mill owners and/or managers in the regions suggest that only a portion of mill residues would be potentially available for bioenergy production (see *2007 Regional Sawmill Survey* section below). Due to high energy costs, most sizeable mills have added sawdust consuming kilns to their facilities, which allow energy co-generation. Assuming that residue used internally for energy production is unavailable for market but that residue currently being sold and or disposed of is, the sawmill survey data suggests that overall, across all states about 82% of the residue generated is potentially available within a competitive market. There is variability between that states with Illinois, Missouri, and Iowa having potential residue availability rates of 60%, 70%, and 71%, respectively. Wisconsin and Minnesota have potentially 95% of their mill residues available to a biomass market. Currently sold residue material is being shipped on average 169 miles from the mill site. Conversely, wood chips are currently trucked over long distances (up to 200 mi), sold at cost, and may be readily available in the region as a bioenergy feedstock.

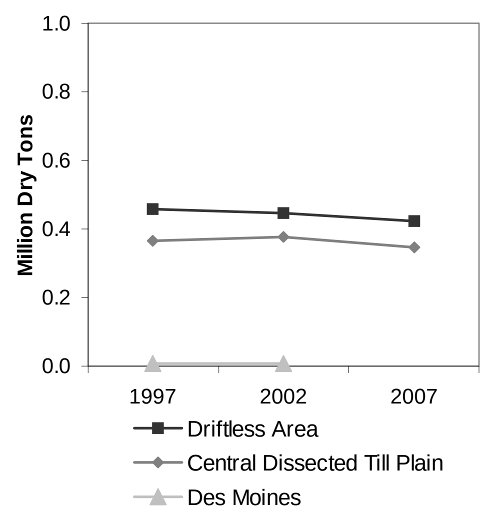

Fig. 11. Total mill residues over time

2007 Regional Sawmill Survey

In 2007, we contracted with Iowa State University's Center for Survey Statistics and Methodology to conduct a telephone survey with owners/managers of sawmills within Iowa and four other Midwestern states. This survey was designed to learn about the production of biomass residue at regional sawmills and the availability of that residue for use as a feedstock within the biofuel market. Specifically, sawmill owners/managers were asked about their mills' total output, total residue generation, a breakdown of residue types (e.g., bark, coarse residues including chips, edgings, trims, or cores, and fine residues including sawdust, planer or lathe shavings), overall fate of residue (e.g., internal usage, market, otherwise disposed), and finally an assessment of their overall willingness to sell residue at various prices in a biofuel biomass market.

Survey questions regarding sawmill output, residue production and type, and residue usage were developed following the general informational format used by the U.S. Forest Service's annual Timber Product Output reporting process. The sample consisted of 86 regional sawmills within Eastern Iowa, Southeastern Minnesota, Southwestern Wisconsin, Northwestern Illinois, and Northeastern Missouri (Table 6). The sample was pulled together using the most recent respective state extension and/or Department of Natural Resource published databases listing sawmills by county (below in the references section see list of directories used). The sample consisted of all sawmills in Eastern Iowa that have kilns, all the sawmills that were reported to produce over 1 MMBF annually in 11 southeastern Minnesota counties, in 24 southwestern Wisconsin counties, in 34 northwestern Illinois counties, and in 24 northeastern Missouri counties.

Table 6. Sawmill survey final dispositions.

Interview Category	IA	IL	MN	MO	WI	Region Total
Beginning sample	13	15	8	31	19	86
Ineligible	0	3	1	6	5	15
Unlocatable	0	0	1	8	0	9
Refused	0	3	0	3	3	9
Completed Interviews	13	6	6	9	9	43
(%)	(100%)	(50%)	(86%)	(36%)	(64%)	(61%)

Fifteen of the sawmills were classified as ineligible. Ten of these were verified out-of-business, three were Amish sawmills with no telephone (in the same Missouri community), and two were not sawmills but rather made products from the byproducts of sawmills. This resulted in an eligible sample of 71 sawmills. Nine of them could not be located. Although it is likely that these nine are also out of business, they were left in the eligible sample because their status could not be verified. Nine (12.7%) of the sawmills refused to participate, and nine (12.7%) were attempted unsuccessfully a maximum number of times. Interviews were completed with 43 of the sawmills, for a response rate of 60.6% (Table 6).

Because of the nature of the sampling process for this survey, it should be noted that the data only represents the reporting mills. Because a full census of all the mills in the designated regions was not conducted, the data presented as "totals" may be viewed as lower bound parameters for these areas.

Total Output and Residue Generation—Surveyed sawmills were asked to report on both their product output levels as well as their concomitant residue waste streams. Within the overall sampled regions, 42 sawmills reported a total of 173 MMBF of processed wood product in 2006

(Table 7). In addition to total product output, 29 sawmills reported the amount of residue they generated in 2006. Across these 29 mills, 190,253 dry tons (US short) of residue were generated (Table 8). Converting the regional product output (measured as MBF) into dry tons (using conversion factors outlined in Mason 2006), the total dry weight of the residue generated was 95% of the dry weight of the primary output, representing a Lumber Recovery Percentage (LRP) of 55% of the raw material (roundwood); that is, 55% of the roundwood input became product and 45% became residue. This finding is within plus/minus 5% of other published LRP's (Fonseca 2005; Steele 1984).

Table 7. Average and total sawmill output volume in 2006 by state (n=42).

State	Number Mills	Mean Output (MBF)	Std Dev Output (MBF)	Min (MBF)	Max (MBF)	Total (MBF)
Iowa	13	4,823	1,185	4	12,000	62,704
Illinois	6	1,992	923	200	6,000	11,950
Minnesota	6	2,783	1,134	1,000	7,500	16,700
Missouri	8	5,875	1,381	260	12,583	47,000
Wisconsin	9	3,903	1,012	1,000	10,000	35,131
Regional total	42			4	12,583	173,485

Table 8. Total residue (dry tons) produced in 2006 by state (n = 29).

State	Number Mills	Residue Biomass (dry tons)
Iowa	11	51,238
Illinois	3	36,050
Minnesota	3	19,940
Missouri	5	44,700
Wisconsin	7	38,325
Regional total	29	190,253

Current Residue Usage—Each sawmill was asked to provide a percentage breakdown of residue type (i.e., bark, coarse residues, and fine residues) and current residue usage (i.e., internal use, marketed, or otherwise disposed). The Illinois and Iowa sawmills surveyed (n = 19) use the largest percentage of their residue for the purpose of on-site energy production (e.g., electricity and kiln fuel), with 40% and 29% internal residue usage respectively. Currently the mills reporting in Missouri (n=8) and Wisconsin (n=8) internally use 7% and 4%, respectively. The Minnesota mills (n=6) claim to use less than 1%. Table C1 in Appendix C displays these data by state.

Assuming that residue used internally for energy production is unavailable to a biomass market but residue in the other categories is, these data suggests that overall about 82% of the residue generated by sawmills in the entire region is potentially available for a competitive biomass market. Specifically, on average, about 71% of the residue produced in the north and south eastern region of Iowa, 60% of the residue produced in the northeast region of Illinois, 100% of the residue produced in the southeast region of Minnesota, 70% of the residue produced in the northeast region of Missouri, and 96% of the residue produced in the southwest region of Wisconsin is potentially available within a competitive market. Using the information in Table 9 below to adjust the total residue generated (Table 8), the lower bound level of residue that would have been available to a biomass market in 2006 is estimated to be about 146,000 dry tons.

Table 9. Percentage of sawmill residue that is potentially available for sale in a biomass market by state and across the region (n = 41).

Region	Residue Produced (dry tons)	Residue Available (dry tons)	Residue Potentially Available for Sale (%)
Eastern portion of Iowa	51,238	36,379	71
Northeast portion of Illinois	36,050	21,630	60
Southeast portion of Minnesota	19,940	19,940	100
Northeast portion of Missouri	44,700	31,290	70
Southwest portion of Wisconsin	38,325	36,792	96
Region total	190,253	146,031	82

Sawmill managers were also asked if they would likely be in business in five years. The majority of the mills reporting (85%) stated that they will likely be in business in five years. These 35 mills currently represent about 176,900 dry tons of residues. Thirteen (38%) of these remaining mills anticipating that their total output will increase over that same period, while 17 mills believe their output will remain the same and 7 plan on decreasing their overall output.

Sawmill managers were additionally asked whether or not they anticipate the internal use of their residues to increase, stay the same, or decrease in five years. Seven (16%) of the mills surveyed believe that their internal usage of residues will increase; 8 (19%) mills state that their usage of residues will likely decrease. See Tables C2, C3, and C4 in the Appendix C for complete data.

Residue Availability at Various Market Prices—While Table 9 displays the amount of residue that is potentially available for sale in a biomass market, Table 10 further scales that availability across various market prices. At $25 per ton, 26 sawmills report that 49,186 dry tons are available to a biomass market. At $35 per dry ton, just over 64,000 tons could be purchased. At $50 dollars per dry ton, 101,680 dry tons could be purchased. Figure 12 displays the cumulative effect higher prices have on residue availability. Availability at various prices tracks very closely with the average reported break-even sale price (at the mill gate) for residues. Minnesota has the highest average break-even price at $39.20/dry ton and Missouri has the lowest at $19.50/dry ton. The regional average is $30.81/dry ton (Table 11). Considering the data in both Tables 10 and 11, $40/dry ton appears to be the lowest

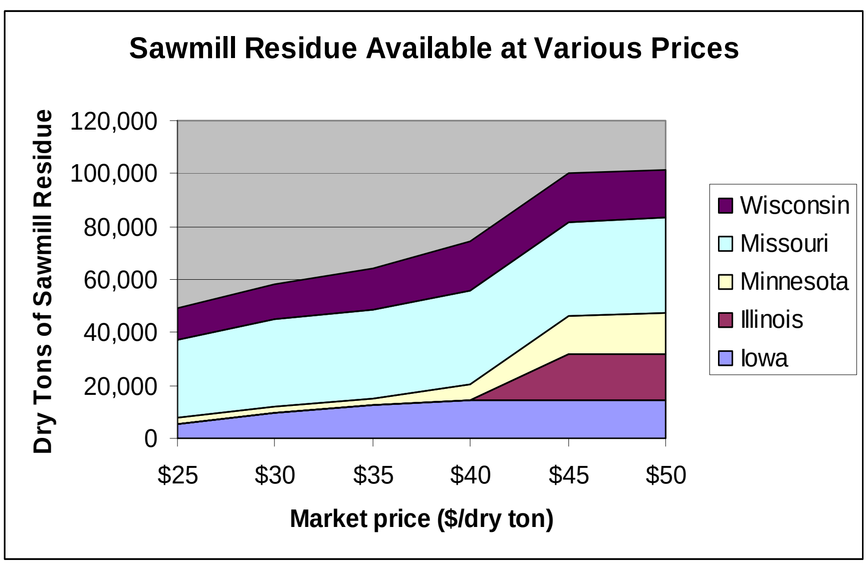

Fig. 12. Total residue available at various market prices ($/dry ton) by state (n = 26).

purchase price that would insure the maximum availability in most areas.

The current biomass market, largely in the form of wood chips, has to date supported fairly long material transportation distances. Across all states the average distance that sawmill residue is currently being shipped is 169 miles. Missouri mills average the longest distance at 230 miles, and Wisconsin the shortest at 120 miles. See Table C5 in the Appendix C for state-level summaries.

Table 10. Total residue (dry tons) available at various market prices ($/dry ton) by state (n = 26).

State	Number Mills	$25/dry ton	$30/dry ton	$35/dry ton	$40/dry ton	$45/dry ton	$50/dry ton
Iowa	10	5,142	9,643	12,505	14,105	14,505	14,505
Illinois	3	0	0	0	0	17,500	17,500
Minnesota	3	2,400	2,400	2,400	6,250	13,950	15,400
Missouri	5	29,600	32,900	33,700	35,700	35,700	35,700
Wisconsin	5	12,044	13,350	15,531	18,575	18,575	18,575
Total	26	49,186	58,293	64,136	74,630	100,230	101,680

Table 11. Breakeven price to market residue from the mill at the mill gate (n = 26).

State	Number Mills	Breakeven Price ($/dry ton)	Std Dev
Iowa	8	$27.38	$18.99
Illinois	3	$35.00	$32.79
Minnesota	5	$39.20	$24.84
Missouri	6	$19.50	$11.01
Wisconsin	5	$39.00	$28.37
Total	28	$30.81	$21.34

All the participating sawmill operators were asked two final open ended questions. One question asked mill operators what their main concerns/questions were regarding the marketing of mill residues to an ethanol refinery. The other question asked what factors other than financial issues would increase their interest in marketing mill residues.

With regard to their main concerns about marketing mill residues to an ethanol biorefinery, across the 43 mills that offered this additional information there were several consistent concerns. While 16% of the respondents stated they had no concerns regarding a biomass market and were largely optimistic about its potential, the majority of sawmill operators did have questions and concerns about the industry in general and the overall strength of this potential biomass market. The following is a brief synopsis of the most consistent comments made by the participating sawmills operators.

About 38 % of the respondents across all five states stated that they were generally concerned about the “sustainability” of the biomass market. Sustainability of a biomass market being collectively defined here by the sawmill operators as a market backed by a “financially stable” local/regional refinery that (in order of importance): 1) “pays on-time” as accorded by a long term contract; 2) provides for “continuity of biomass purchasing” (i.e., there would be year-round material collection largely due to limited storage capacity), and 3) is a refinery that is capable of receiving multiple residue types with limited to no pre-processing (e.g. a few mills mentioned concerns about having to dry and/or sort materials on-site). Just over 16% of the respondents expressed concerns about the overall profitability of biomass as an ethanol feedstock with many sawmill operators skeptical that such a market could pay as well as current markets (e.g., chips). A few respondents also questioned the overall profitability of ethanol in general. Transportation of materials was mentioned by about 12% of the respondents as something that they could not currently provide – in other words most material transportation would need to be arranged by the biorefinery. There was also repeated concern (12% of the respondents) about potential transaction costs associated with "dropping current customers." These concerns are associated with issues such as: the need to set up arrangements with a new client, the ethical aspects of leaving current customers "high and dry", the potential need to "go and get old customers back" if the ethanol biomass market fails, and the risk associated with switching from a somewhat diverse client base to just one client (the refinery). There were also a few comments associated with some ancillary benefits of an increase in ethanol refinement such as less reliance on fossil fuels and potential environmental benefits (some associated with lower fossil fuel impacts and some associated with less wood based waste and disposal needs). There were a few who had questions regarding the energy balance associated with the refinement process (e.g. a belief that ethanol production is not energy efficient). One mill operator suggested that, if the ethanol industry was going to look toward woody feedstock resources, then it should invest in local and regional forest management.

The following are the general concerns and/or questions by state.

- Iowa (n = 13): Mill operators in Iowa were mostly concerned about the sustainability and overall profitability of the market.
- Illinois (n = 6): Mill operators in Illinois were mostly concerned about the sustainability of the market and had questions about delivery of materials.
- Minnesota (n = 5): Mill operators in Minnesota had the most variability in their comments with general concerns ranging from the sustainability of the market, overall profitability, delivery issues, and concern for current customers.
- Missouri (n = 9): Mill operators in Missouri were generally the most optimistic about a biomass market yet with a few mills expressing concerned about the sustainability and overall profitability of the market.
- Wisconsin (n = 9): Mill operators in Wisconsin were overall very concerned about the sustainability of the market but did express that such a market would likely be good for the environment.

In terms of the factors that would increase a mill's interest in selling residues to a refinery, just over 42% of the 43 mills responding across the five states stated that only financial issues (e.g. profitability and consistency in the market) matter regarding their interest in selling mill residues. One mill operator stated that biomass markets might be an excellent option for sawmills because of the "slowing paper industry." Still, about 14% of the respondents did mention that supplying residues might provide other business related benefits such as lowering residue disposal costs and help in keeping the mill clean. Additionally, a few operators did mention that they would be more inclined to supply their residues if doing so: had limited impact on their current business, was "easy to do," and proved to be good for the environment.

In sum, 43 sawmills covering NE and SE Iowa, SE Minnesota, SW Wisconsin, NE Missouri, and NW Illinois) participated in a regional biomass assessment survey in Fall 2007. The survey covered sawmill total output, total residue generation, a breakdown of residue types (i.e., bark, coarse residues, and fine residues), overall fate of residue (i.e., internal usage, market, otherwise disposed), and an assessment of their overall willingness to sell residue at various prices in a bio-fuel biomass market. In 2006, based on the estimates provided by 29 sawmills, just over 190,000 dry tons of mill residue was generated. Because we were not able to survey all mills active in the region, this can be thought of as a lower bound estimate of residue production in the area of interest. Some mills surveyed actively use residues on-site for energy co-generation; thus, not all residue produced is available for purchase. Instead, 82% of residues, approximately 146,000 dry tons total, is potentially available for sale in a competitive biomass market across all five states. At reported mill gate break-even prices for residue biomass ($30.81/dry ton; 28 mills reporting), a little over 58,000 dry tons would be available. At $50/dry ton, almost 102,000 dry tons of biomass would be available for sale in a biomass market. The present, existing biomass market appears competitive at an average transportation distance of 169 miles. Biomass is largely transported in the form of wood chips.

Stumpage Prices

The appropriate round-wood comparison raw material for biomass is pulpwood. Pulpwood trees are any commercial tree species that do not have the size (typically <8 in diameter) or quality (e.g. due to stem defects) to make other wood products. Sawtimber stumpage (the price of a tree still on the stump), depending on species can be upwards of an order of magnitude higher than pulpwood stumpage.

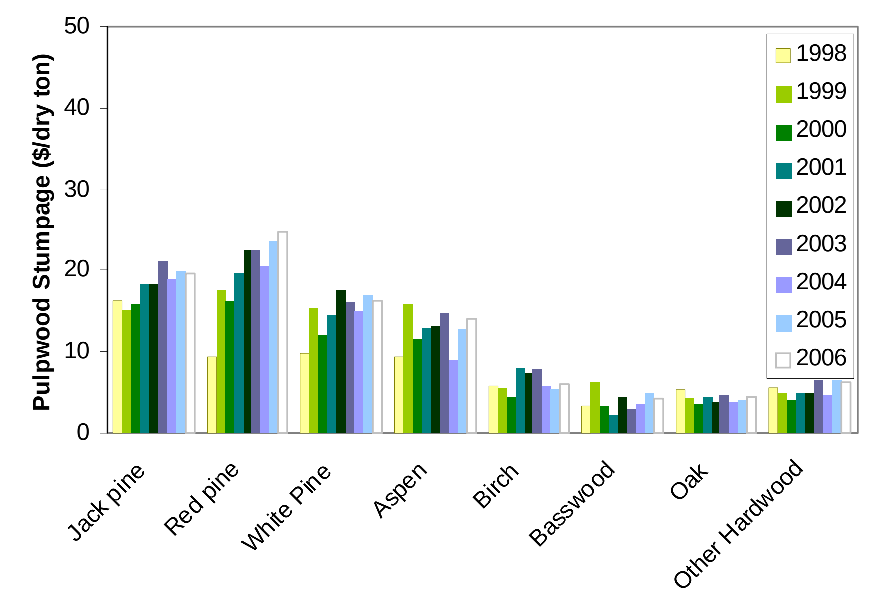

Fig. 13. Pulpwood stumpage in real terms in Wisconsin, 1998-2006

Pulpwood prices are reported regionally or state-wide, and with little consistency among agencies. Here we report pulpwood stumpage prices for Wisconsin (WI DNR 2007), Minnesota (MN DNR 2007a), and Illinois (UIE 2007); stumpage prices for Iowa and Missouri are not published. Wisconsin prices are based on a regional basis; we used reports from Richland Center and Eau Claire, WI, which fall within or near the Driftless Area. Minnesota and Illinois prices are reported statewide. Stumpage in Minnesota largely reflects its value within the northern portion of the state, where the majority of pulp and OSB facilities are located. The prices are likely inflated for the Driftless Area, where no such facility exists. This inflation can be seen in the data, when comparing between the Minnesota and Wisconsin data (Figs. 13 and 14). For example, pulpwood prices for pine and aspen are $10 higher on average in Minnesota than Wisconsin for the period 2002-2006.

Some care need to be taken when examining pulpwood prices regionally. Not all sources of price information are consistent in their reporting procedures, units used and species inclusion. Here, all dollars are listed in real terms—that is, they are listed in constant dollars and inflation is not included. Some individual species show greater market volatility than others. For example, aspen pulpwood stumpage prices have been highly variable over time both in Wisconsin and Minnesota (Figs. 13 and 14). Reasons for this volatility vary, but may include (a) an increase/decrease in harvest rates as part of a general gradual trend or as a singular reduction due to weather constraints, (b) new procurement strategies by mills (e.g., higher imports regionally and from Canada), (c) an increase/decrease in the value of same species sawtimber stumpage, (d) a regional or national shortage/glut of particular species, (e) new technology that makes a particular species more/less desirable, and (f) the arrival of a pest or pathogen, or a sudden increase in its activity. Regionally, pulpwood prices can respond rapidly to industry contraction. For example, the Minnesota Department of Natural Resources reports that a large drop (57%) in aspen pulpwood stumpage from the period July 2005 – June 2006, as compared to October 2006 – March 2007, was the result of both several Oriented Strand Board (OSB) plants closing (in some cases temporarily) and a general slowdown in production at several regional mills. Overall, pulpwood prices are susceptible to national and international competition in industries that use both sawtimber and pulpwood as raw materials. For example, increased OSB manufacturing in Canada and the Southwest U.S. as well as volatility in housing starts can impact pulpwood prices regionally.

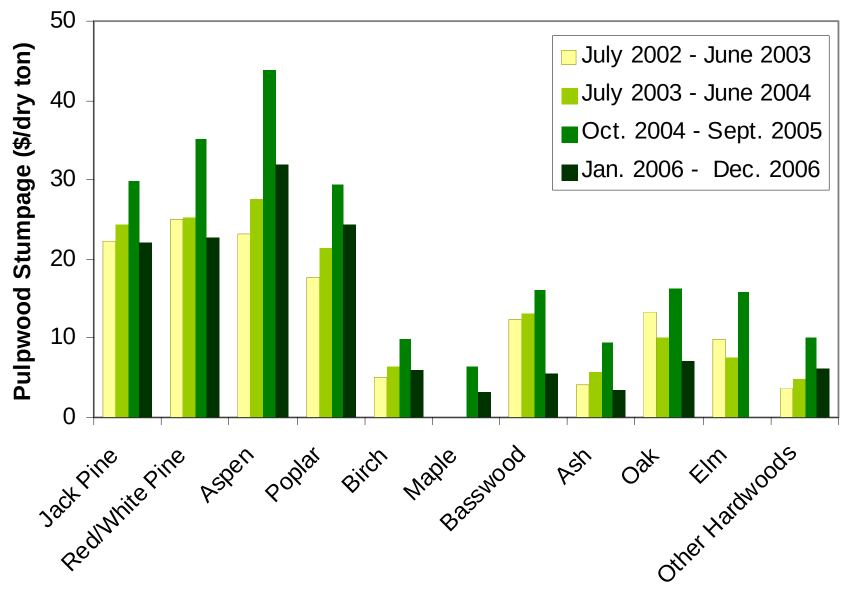

Fig. 14. Pulpwood stumpage in real terms in Minnesota, 2002-2006

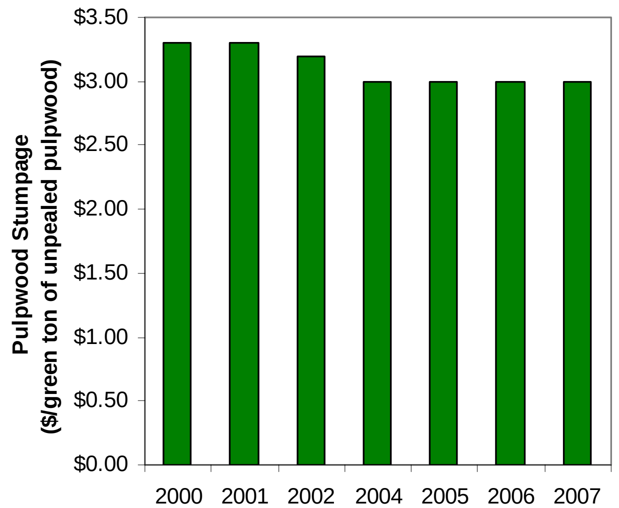

Fig. 15. Pulpwood stumpage in real terms in green tons in Illinois, 2000-2007

Short-Rotation Woody Crops

Short-rotation woody biomass crops offer important advantages that recommend them as a critical component of the overall feedstock supply system. Using currently available tree selections and plantation methods, an average of over 8 dry tons/ac/yr (18 MG/ha/yr) of lignocellulosic feedstocks can be grown on a variety of soils and topographic positions (Table 12). Some trees like the poplars are easier to breed, select, and propagate than most other crop plants, and the poplar genome has been sequenced (Hall et al. 1989, Reimenschneider et al. 2001, Tuskan et al. 2006).

Table 12 shows the biomass production capabilities of three short-rotation woody cropping systems based on research in Iowa (Goerndt 2005, Coyle et al. 2008, Hall unpublished data). Information on Years 1-8 are based on empirical data, while Years 9 and 10 are based on a growth model and may be over-estimates of overall production potential. Based on previous studies on a variety of soils in Iowa (Goerndt 2005), the hybrid aspen clone 'Crandon' has a production curve that starts at less than two dry tons of lignocellulosic biomass/acre over the first three years, but builds to a current annual yield of over 39 dry tons/ac (87 MG/ha) by age 10. In addition, Crandon has relatively high cellulose, low lignin, and low extractive content (Dickson et al. 1974). Other, more productive clones are under development at ISU (Hall unpublished data).

Table 12. Biomass (dry tons/ac/yr) production by short-rotation woody cropping systems according to plantation age (Goerndt 2005, Coyle et al. 2008, Hall unpublished data). Data are not available (na) for years 9 and 10 with cottonwood.

Species/Land type	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Aspen (Crandon clone)								
Bottomland	2.4	3.5	4.7	5.9	7.3	8.6	10.1	11.6
Slopes	0.6	1.0	1.7	2.5	3.4	4.5	5.8	7.3
Agricultural land	0.8	1.6	2.7	4.1	5.8	7.9	10.4	13.3
Silver maple								
Bottomland	0.1	0.2	0.5	0.8	1.2	1.8	2.5	3.4
Slopes	0.1	0.2	0.4	0.5	0.8	1.1	1.4	1.8
Agricultural land	1.0	1.6	2.3	3.2	4.2	5.4	6.6	8.0
Cottonwood								
Bottomland	1.9	2.7	4.0	4.6	4.9	5.1	na	na

At 6% real rate of return, the breakeven farm gate price for cottonwood biomass from plantations is estimated to be $69/dry ton (Coyle et al. 2008). Economic returns improve significantly in the shorter sprout cycles possible with the hybrid aspens because there are fewer inputs, primarily one fertilization per cycle. Hybrid aspen possess the capability to sprout prolifically from their roots following initial and successive harvests once the trees are well-established, cutting production cycles at least in half. Specifics on the production capacity of these systems under coppicing currently do not exist, however. The environmental benefits of having a permanent root system in place, no tillage after the establishment year, nutrient recycling with very low leakage, and desirable wildlife cover for most of each growing cycle can also be significant (Schulte et al. 2006).

The key drawback to the use of short-rotation woody crops, however, is the lag time in bringing a new planting to full production. To potentially overcome this hurdle, research has been funded to develop a multi-cropping system combining forage triticale, a shallow-rooted, winter annual that completes its growth before the dry part of our growing seasons, with hybrid aspen trees. The triticale crops produced during the tree establishment period will substantially reduce the time lag in providing biomass to a biorefinery.

Our ad hoc interviews with public and private foresters in the region suggest that, given a profitable market and/or policy incentives, landowners would be willing to invest in short-rotation woody crops. According to one of our interviewees, many Iowa landowners “would love a plantation market.” Historically, there has been strong interest in tree farms in the state, though variable by locality. In east central Iowa, foresters expected that at least 5% of landowners would likely find short-rotation woody crop plantations financially appealing. In west central Iowa, it is estimated that less than 5% of the area forest landowners would be interested. In NE Iowa, SRWC plantations may be amenable as a component of riparian buffers and on marginal lands (e.g., abandoned pastures). In central Iowa, there may be some community backlash to harvesting trees, putting the feasible percent at about 1%.

Marginal farmlands comprise the most likely locations for citing woody biomass plantations, although some landowners may be interested in planting dynamic windbreaks in crop fields, on field margins, or around farm buildings. In particular, foresters saw floodplains and bottomlands as having high potential for SRWC plantations. Existing plantations in Iowa are now located in riparian areas and average 3-5 ac in size. Market outlets would draw further interest, but still small loggers want a minimum of 10 MBF (21.6 dry tons), excluding walnut, to work on a site.

As a coarse estimate of the extent of marginal farmlands in the region, we summarized the number of acres actively enrolled in the Conservation Reserve Program (CRP) (FSA 2007). The Central Dissected Till Plain poses the highest density of CRP acres (Fig. 16), with over 2 million acres enrolled at present. The density of CRP acres are also high in some portions of the Driftless Area, however, with 871,000 ac enrolled across these counties. Given the amount of prime farm land and housing development pressures around Des Moines, this area has the lowest density of CRP acres, at 153,000 acres overall.

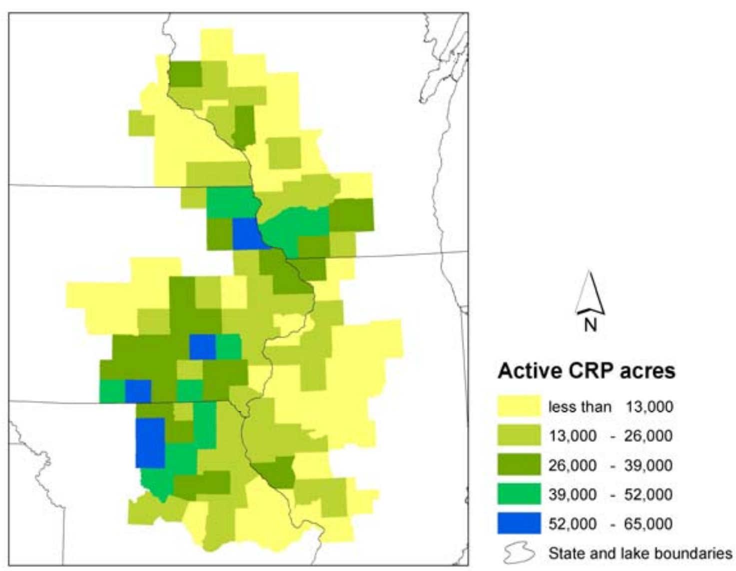

Fig. 16. Active Conservation Reserve Program acres (as of October 2007).

Before plantation wood can be available in quantity, several things must happen. More rural landowners will need to become familiar with tree plantations and what they can offer in producing biomass energy feedstocks. Government conservation programs will need to recognize the dual role these plantations can fill and be willing to help cost share establishment costs to encourage entry into the production of these woody crops. Interested biorefineries will need to work out contract arrangements that provide some annual income for landowners in between harvests while still providing incentives for good management that will optimize plantation yields. The production of planting stock will need to be geared up to support large-scale plantings. And, the eight to ten year start-up period for the first plantations to mature must be completed. To estimate what might be realistically produced, we have assumed that 10 % of the CRP acreage in each region is converted to tree plantations that continue to protect the environment while producing a biomass crop. Using aspen on the steeper ground and selected bottomlands, and cottonwood on the areas prone to flooding, an average annual production of 5 dry tons/acre should be achievable (Table 12). Given these assumptions, 1 million dry tons of biomass could be produced annually in the Central Dissected Till Plain, over 217,000 dry tons in the Driftless area, and over 38,000 dry tons in the Des Moines area.

The foresters we interviewed did not presently see the steep lands in NE, S, and W Iowa as amenable to plantations, due to management difficulties imposed by the topography. Previous research shows, however, that aspen could be highly productive under these circumstances (Goerndt 2005). Further challenges perceived by the foresters are the many absentee landowners in these portions of the state, who own land for hunting purposes and therefore favor deer habitat over other interests. Much of the new tree plantings in NE Iowa are for wildlife habitat; for example, about 10 million tree seedlings/year are planted in wildlife-oriented CRP. They also suggested that landscape aesthetics and the use of non-native species or genetically modified trees may be of concern. Convincing landowners, and society in general, that plantation management is a "good" use of land may be difficult. In particular, it may be challenging to convince many landowners that the work involved in arranging for biomass removal and the potential "mess" of harvesting is "worth" it. Profit motivations may or may not be high enough to alleviate these concerns. Pairing the possibility for profit with and cost share program to alleviate initial startup costs may be a powerful magnet.

Waste Streams

The waste managers and recycling businesspersons we interviewed suggested a substantial woody biomass resource within municipal waste streams. Table 13 provides estimates of woody or wood-derived biomass within the waste streams of the three study regions in total, and four urban centers falling within them. These estimates are based on statistics calculated by a waste stream categorization study conducted in 2005 in Iowa (Iowa DNR 2006). Although large amounts of wood waste are produced annually within the region (Table 13), much of this material is diffuse and difficult to collect. Wood waste associated with urban centers is more concentrated in terms of production and waste collection services constitute an existing concentration mechanism. While there is already an existing market for compostable and mixed recyclable paper in the region, much of the waste wood is currently landfilled and thus readily available, pending sorting and transportation costs. Further, waste paper is trucked over long distances at high transportation costs (e.g., to New Mexico, Texas, Wisconsin); a regional buyer may be able to out-compete these distant purchasers. The infrastructure for recovering construction and demolition wood wastes has been developed in Des Moines and could serve as a model for other areas.

Table 13. Human population levels and wood-derived biomass produced annually in dry tons as municipal waste within three study regions and four urban centers.

Region/City	Population	Compostable paper	Mixed recycle-able paper	Non-treated wood	Treated wood
Driftless Area	2,578,999	119,347	128,168	72,013	97,429
Central Dissected Till Plain	4,031,516	186,564	200,353	112,571	152,302
Des Moines	651,280	30,139	32,367	18,185	24,604
Davenport	377,291	17,460	18,750	10,535	14,253
Des Moines	534,230	24,722	26,550	14,917	20,182
Dubuque	57,696	2,670	2,867	1,611	2,180
Ft. Madison	10,715	496	533	299	405

Urban forests and their waste streams constitute another important source of biomass from wood. Although a portion of the biomass from urban forests is captured in the non-treated wood category of Table 13, much of this material currently ends up as firewood or mulch for landscaping. As there is no existing agency monitoring this industry, determining exact percentages and existing markets would require further investigation via a survey instrument and interviews. While some baseline level of wood biomass from urban forestry operations likely exists, larger quantities are ephemerally available, associated with ice storms, wind storms, or tree diseases. Ice storms may be the most consistent of these disturbances; according to Harvey and Packard (1967), severe ice storms that cause significant tree damage affect portions of Iowa at least every other year. The arrival of the emerald ash borer, though unfortunate for forests in the region, could provide a glut of woody biomass in a very short period.

Overall Woody Biomass Potential

The Driftless Area and the Central Dissected Till Plain possess the capacity to support a cellulosic biomass facility at present (Table 14). On an annual basis, the Driftless Area currently produces 11.5 times the raw material required by a facility using one-half million dry tons of woody biomass per year. Although allocated over a larger area, the Central Dissected Till Plain produces 14.8 times the required material. The key issues to overcome in these areas at present are inefficiencies in the access and transport of available material.

Our analysis further suggests that the Des Moines area could support a pilot to moderate-scale biorefinery, which could access the substantial amount of wood waste generated in and around the city as well as a substantial resource of low-quality hardwoods found in natural forests in the area (Table 14). If sited to the south of Des Moines, such a facility would be within an economical haul distance of both municipal wood wastes and the more heavily forested areas of southern Iowa and northern Missouri.

These estimates, however, do not take into account the potential for the development of short-rotation woody crops in these regions. Our conservative estimate suggests that the biomass production potential of these systems is substantial, especially on the Central Dissected Till Plain, where a higher proportion of the farmland is marginal for growing rowcrops. If short-rotation woody crops plantations were encouraged within economical haul distances of biorefineries, they could simplify the collection issues associated with most other sources of woody biomass and solve storage issues associated with other cellulosic biomass crops. To make these systems feasible, profitable markets for woody biomass need to be verified, mechanisms that encourage landowners to plant short-rotation woody crops need to be developed, and financial incentives to get through the initial production time lag associated with these systems need to be established.

Table 14. Potential annual biomass resources and their energy value for three regions.

	Biomass potential (dry tons/year)		
Biomass type	Driftless Area	Central Dissected Till Plain	Des Moines
Raw material direct from natural forests (net growth)	4,244,976	5,855,460	247,994
Logging residues	644,287	549,188	3,883
Wood industry residue	424,001	347,635	n/a
Municipal paper wastes	247,515	386,917	62,506
Municipal wood wastes	169,442	264,873	42,789
Total	5,730,221	7,404,073	357,172

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Appendix A. Common and scientific names of tree species evaluated.

Common name	Scientific name
Eastern redcedar	*Juniperus virginiana*
Jack pine	*Pinus banksiana*
Red pine	*Pinus resinosa*
Eastern white pine	*Pinus strobus*
Boxelder	*Acer negundo*
Black maple	*Acer nigrum*
Red maple	*Acer rubra*
Silver maple	*Acer saccharinum*
Sugar maple	*Acer saccharum*
River birch	*Betula nigra*
Paper birch	*Betula papyrifera*
Bitternut hickory	*Carya cordiformis*
Pignut hickory	*Carya glabra*
Shellbark hickory	*Carya laciniosa*
Shagbark hickory	*Carya ovata*
Black hickory	*Carya texana*
Mockernut hickory	*Carya tomentosa*
Hackberry	*Celtis occidentalis*
White ash	*Fraxinus americana*
Black ash	*Fraxinus nigra*
Green ash	*Fraxinus pennsylvanica*
Honeylocust	*Gleditsia triacanthos*
Butternut	*Juglands cinerea*
Black walnut	*Juglands nigra*
Osage-orange	*Maclura pomifera*
Red mulberry	*Morus rubra*
Eastern hophornbeam	*Ostrya virginiana*
Sycamore	*Platanus occidentalis*
Eastern cottonwood	*Populus deltoides*
Bigtooth aspen	*Populus grandidentata*
Quaking aspen	*Populus tremuloides*
Black cherry	*Prunus serotina*
White oak	*Quercus alba*
Swamp white oak	*Quercus bicolor*
Northern pin oak	*Quercus ellipsoidalis*
Shingle oak	*Quercus imbricaria*
Bur oak	*Quercus macrocarpa*
Chinkapin oak	*Quercus muhlenbergii*
Pin oak	*Quercus palustris*
Northern red oak	*Quercus rubra*
Post oak	*Quercus stellata*
Black oak	*Quercus velutina*
Black locust	*Robinia pseudoacacia*
Black willow	*Salix nigra*
American basswood	*Tilia americana*
American elm	*Ulmus americana*
Slippery elm	*Ulmus rubra*

Appendix B. Complete responses from six professional Iowa foresters.

In late 2007, five Iowa Department of Natural Resource district foresters and one private forestry consultant were asked a series of questions seeking their experienced opinions on the potential for woody biomass to be supplied from Iowa's privately owned forests to a biomass market. The individuals interviewed are among the most knowledgeable professionals in this study's analytical region. The following lists questions asked and provides their complete responses.

In natural stands, what forest silvicultural (e.g., TSI, seed tree harvest, clear cut harvest) or harvest (e.g., cut-to-length vs. whole tree, chip vs. bundle) systems do you see as offering the potential for woody biomass collection?

- Managing for biomass ultimately does not seem all that feasible. Biomass as secondary goal to TSI or other intermediate treatments such as invasive species eradication might be possible – but expensive. However there may be some areas – poor quality bottomlands for example that could possibly use whole scale conversion – clearcut style – simply to start over again. Harvesting from CRP would likely provide biomass – if it were permissible.
- TSI - Crop tree release - 20 to 40 ac some larger most by girdling for speed and cost. No chipper since last tornado.
- Crop tree release. <20% clearcut typically about 40 acres, mostly selection cuts. Most material left on site - some removed for landowner or logger fire wood. Most all tops left on site after harvest. No on-site chipping.
- Even age silvics. Equipment - big equipment (drag with skidder, attach to tree and drag out). Whole tree usage for better utilization. No one wants to make chips from tops or low density stands.
- River bottom species - only place to do real clear cuts. On oak sites need the slash to protect seedlings from deer. Weed tree/crop tree has too few stems and only 10 acre in typical size.
- Maybe on large ownerships of 150 acre size. Mechanization also works best on bottomlands. Western part of state has a lot of underutilized cottonwood. But pallet market has stayed strong. Hackard Pallet mill NE Ottuwa - these mills have chippers and anything that they can use - bark is a plus. Divide into hard and soft woods?

Given that the biomass energy market won't be able to compete for sawlogs, what other woody material do you see as having the potential to be collected for biomass?

- Pulpwood might make sense particularly in SE Iowa (b/c of pulp mill contraction). Sawmill residue. TSI materials – lots of overgrazed forest land in Iowa – Invasive management. Not a lot of high quality timbers period so a market for low quality might spur some cutting.
- Mostly TSI - Most harvests are small groves that don't generate much size. Only 3-5 large sales/yr maybe only 10% of land owners go through this district forester. 88 acres and 20 acre tree planting - Jack Minor - mostly ash. Planted near Somerset. Black Locust, Hybrid poplar.

- Few portable sawmills - most simply leave residue.
- Average 5-6 acres for a clear cut; 20-30 acres for selective harvest.
- NE Iowa stands could really use a temporary clearing of basswood and maple. Could use elm because if it stays there, will throw too many seedlings. Emphasis has shifted to bitternut because of its fast growth - good sawlogs.

Q3. Estimate the costs associated with removing these different types of materials:
• 2-4" diameter material of mixed species,
• 4-10" material of mixed species,
• >10" of low quality, non-sawlog material--either because of species or defects.

- $75-200/ acre across all sizes.
- A fuelwood operator between Ogden and Boon could maybe give some answers here.
- Not sure.
- Cost of skidding - nothing; cost of chipping? Wont be cutting 10" elm; don't have the volume for mechanized equipment.
- Need in the woods chipping to make TSI profitable.

What percentage and sizes of operational wastes do you feel should be left behind to protect soil and habitat qualities?

- At least 33%. More if there is a high potential for erosion of if natural regeneration can be strongly impacted by herbivory.
- Blank.
- Not sure.
- Nutrient cycling through leaves. Already so much habitat therefore not of concern.
- 50%.

What percentage of landowners that you work with do you expect to be amenable to woody biomass collection from natural forests?

- Potentially a high percentage. Every forest management plan recommends cutting something – TSI, crop tree release, weed tree removal, natural regeneration prescriptions. Key will be to point out that a landowner can still achieve non-market goals and cuts trees at the same time. However, at least 25-40% of the landowners would have strong attitudes against allowing large equipment on land and in many cases the land is somewhat fragile (e.g. steep slopes, includes large gullies with large scale active erosion) that could not handle large equipment. There could possibly be a lot of cutting but a large proportion of it not extracted because of land concerns.
- Majority would if they were managing for timber - 20-25%?
- 25-33% would be readily agreeable. Such a market would likely spur additional and new TSI.

- If it meant higher timber prices <= 100%. Challenge: pulling out whole tree damage other material in selective cut. About 30% of the landowners would be willing to harvest.

How about plantations: what portions of the landscape do you see as amenable to short-rotation woody crop plantations? Or, how do you see these short-rotation woody crop plantations fitting into the landscape?

- High potential for flood plains (assuming species used can handle it), bottomlands – other areas with similarly low opportunity costs. Strong interest in tree farms. One guy in particular is converting all of his pasture land into walnut plantations to be managed for veneer.
- Most are now riparian 3-5 acres. Markets would draw interest but still small loggers want a minimum of 10MBF (excluding walnut).
- Lots of steep land. Lots of absentee landowners. Lots of hunting interest and therefore deer browse interest.
- Lots of steep land. Lots of absentee landowners. Lots of hunting interest and therefore deer browse interest.
- Many landowners would love plantation market.

What percentage of landowners do you think would be interested in establishing plantations of short-rotation woody crops?

- At least 5% would likely find it financially appealing; there may be some community backlash with low social acceptability (e.g. regarding harvesting) putting the likely percent about at 1%.
- Less than 5%.
- Not sure.
- Amenable to treed riparian buffer and on marginal lands (e.g., abandoned pasture. Tree planters?

What would be some landowner motivations for engaging in the biomass market, whether from natural forests or biomass plantations?

- Finding a use for marginal cropland. Many might do it even at breakeven if it makes marginal land "productive". Probably a lot of landowners/farmers "on the fence" – want to do something but costs are high (at least that is the perception). Cost share availability is usually enough to "push at least some off the fence". A profit possibility & cost share would be a powerful magnet. There might be a lot of people who could become excited about biomass for ethanol production and that context would likely make it seem more socially acceptable. The biggest constraint would likely be size of individual parcels and or dual use of land for grazing.
- A market would really entice more land owners, especially farmers who make their living off the land. Disincentives - too small a return. Absentee landowners might not feel they could keep track and they might be concerned about hunting.

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- Economic - but across the board aesthetics. 10 million tree seedlings/year went to wildlife oriented CRP. Frequent harvests and econ incentives to do it. . Disincentives - infrequent harvests; cost of removal. No apparent constraints due to parcel size.

Are there existing operators and equipment in your region that would likely move into collecting and delivering biomass if a reasonable market develops?

- A lot of the calls – more and more – are coming from farm managers who happen to be responsible for wooded grazing lands and riparian areas. Inquiries regarding cost share for fencing and Forest Reserve and CRP compliance regarding tree management. Fairly savvy group of business people however and likely would be highly interested in making these lands more profitable. In terms of cutting biomass there is a lot of hydraulic attachment style (for Vermeer and John Deer tractors, Bobcats) that can easily cut up to 8-9" stems – so potentially a lot of landowners would have their own equipment if there was a market for the wood. In terms of collecting and delivering biomass not sure. Log buyers would likely have a stake in biomass particularly if pulp is mixed in the sale. Loggers and hauling is usually third party.
- Two brothers sold tech company and wanted to move to Iowa. Heartland was helping develop the urban.
- Don't know of any. New market would lead to new people.
- If you had market and acres then yes. Initially, would do with what they have (pick up more $ per tree) but if market develops, then likely so.
- Nature hates a vacuum. JC Services, DSM do volume chipping. Contact Alliant Energy - they have Asplundh under contract for storm damage.

What price do you think it would take at the farm gate to attract significant interest in supplying waste wood from intermediate treatments and regeneration harvests?

- At least 1.5 times the costs but may not be enough to alleviate concern about social issues (again backlash against harvesting). At 2 times the costs of extraction most social concerns will disappear.
- Going rate was $20/ton from Ft. Madison on occasion. He thinks $30/ton would do it.
- Not sure.
- $40-50/wet ton - pulp price

What other challenges do you see to developing a biomass market in your region?

- Depending on the plantation, if non-native species or GMO trees are used there may be concern. Landscape aesthetics is also a big deal. Convincing people – general society – that plantation management is a good use of land may be tough. Convincing many landowners that the trouble and potential "mess" of harvesting is "worth" it may be a trick. Everything associated with the troubles of promoting good forest management in general will be relevant. Profit motive may not be high enough to alleviate concerns – (see Q10).

- Mid American Energy will lower prices and more windmills.
- None.
- Getting the plants built. If market there people will figure out how to supply. How much will plant pay/ton compared to corn.

Appendix C. Additional Summaries of Mill Survey Data

Table C1. Percentage breakdown of residue type and current residue usage for each state (n=41).

State	Residue Usage	Bark	Coarse Residue (chips, slabs, edgings, trims, cores, etc.)	Fine Residue (Planer or lathe shavings and sawdust)
Eastern Iowa (n = 13)	% of total residue	28	53	19
	% residue used internally for energy	4	42	32
	% residue sold	86	47	68
	% residue disposed of	10	11	0
Northeast Illinois (n = 6)	% of total residue	13	70	17
	% residue used internally for energy	48	42	25
	% residue sold	52	58	58
	% residue disposed of	0	0	17
Southeast Minnesota (n = 6)	% of total residue	24	45	27
	% residue used internally for energy	0	0	1
	% residue sold	100	100	99
	% residue disposed of	0	0	0
Northeast Missouri (n = 8)	% of total residue	24	41	32
	% residue used internally for energy	0	8	13
	% residue sold	88	69	60
	% residue disposed of	12	23	20
Southwest Wisconsin (n = 8)	% of total residue	41	41	18
	% residue used internally for energy	0	6	11
	% residue sold	100	94	89
	% residue disposed of	0	0	0

Table C2. Sawmill response to whether or not they will be in business in 5 years (n=41).

State	Do you think that your mill will be in business in 5 years?		Total
	Yes	no	
Iowa	11	2	13
Illinois	4	2	6
Minnesota	6	0	6
Missouri	8	1	9

Wisconsin	8	1	9
Regional total	35	6	41

Table C3. Sawmill response from those mills who will be in business in 5 years regarding their total output (n = 35).

	Over the next 5 years, do you think your output will…			
State	Increase	stay the same	decrease	**Total**
Iowa	3	6	2	11
Illinois	1	1	2	4
Minnesota	3	2	1	6
Missouri	2	5	1	8
Wisconsin	4	3	1	8
Regional total	13	17	7	37

Table C4. Sawmill response to whether or not they anticipate their internal use of their residues to increase, stay the same or decrease in 5 years (n = 43).

State	**Next 5 years, internal use of mill residue will...**			**Total**
	Increase	Stay the same	Decrease	
Iowa	4	7	2	13
Illinois	0	4	2	6
Minnesota	1	5	0	6
Missouri	2	5	2	9
Wisconsin	0	7	2	9
Regional total	7	28	8	43

Table C5. Farthest distance that sawmill residue is currently being shipped by state (n = 38).

State	**Number Mills**	**Mean Distance (miles)**
Iowa	12	141
Illinois	6	227
Minnesota	6	163
Missouri	7	230
Wisconsin	9	120
Regional total	40	169