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Woody biomass in the U.S. Cornbelt? Constraints and opportunities in the supply

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ABSTRACT

The U.S. is clearly entering a new era of liquid fuel production; one that will be characterized by increasing degrees of renewable raw materials. Woody biomass is an especially compelling feedstock choice where available. Significant questions, however, exist regarding the potential of some landscapes to provide this feedstock. In an effort to answer these questions, we performed an exploratory spatial assessment of woody biomass production and supply capabilities in two-ecoregions Mississippi River corridor within the US Cornbelt. We used existing forest/timber inventories and conducted in-depth interviews with large regional sawmills to understand the accessibility of woody biomass from natural forests, availability of and general costs associated with woody biomass in the existing timber industry, and potential for production from short-rotation woody crop plantations. On an annual basis, taking into account only the annual net growth of non-sawlog species the Midwest Driftless Area currently produces 3.14 times the raw material required by a hypothetical facility using one-half million dry tons of woody biomass per year. Although allocated over a larger area, the Central Dissected Till Plain produces 3.94 times the required material. Throughout the entire region there would be an additional lower bound estimate of 107,000 dry Mg from easily transportable sawmill residues. The ecological state of US Cornbelt forests stand to gain from a developed market for woody biomass as proper woodland management to harvest trees, preserve wildlife, and reduce risk from disease, pests, and invasive species typically involves harvesting the low-value trees that will by and large drive the woody biomass system.

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1. Introduction

The United States is clearly entering a new era of liquid fuel production; one that will be characterized by increasing use of renewable raw materials. The 2007 US Energy Independence and Security Act (EISA), among other purposes, enhanced the Renewable Fuel Standard (RFS) that will require liquid fuel producers to blend at least 136.27 B liters (36 B gal) of biofuel by 2022 [1]. Ambitiously, EISA stipulates that 60.56 B liters (16 B gal) of total US bio-ethanol output must be cellulosic ethanol made from biomass (ligno-cellulosic) feedstocks. Optimism regarding cellulosic ethanol possibilities is largely centered around the so called "Billion-ton Study" which calculated an annual US biomass inventory of roughly 1.42 B dry Mg (1.3 B dry US tons) of biomass that is considered technically available and sufficient to provide feedstock for enough cellulosic ethanol to replace upwards of 30% of the US's current fossil fuel based transportation fuel demand [2]. The three main US

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"Billion-ton Study" biomass categories based on calculated technical availability are: 1) perennial crops, e.g., switchgrass (*Panicum virgatum*) and short-rotation hybrid poplars (*Populus X species*) which amount to roughly 35% of total US annual biomass potential; 2) corn stover (e.g., stalk, leaf, husk, and cob remaining in the field following the harvest of corn grain) amounts to ≈20% of total US biomass; and 3) woody materials from natural forest systems (including logging and sawmill residues) amount to ≈13% [2]. Because of calculated physical abundance and available land area, crop residues and potential dedicated perennial crops have been touted as the dominant feedstock options for cellulosic ethanol production in the US Cornbelt region [3]. Yet despite the legislated impetus and the apparent physical abundance of biomass materials, the US cellulosic ethanol refinement industry remains largely experimental in scale. As of summer 2009 US cellulosic ethanol production was minimal with a capacity of roughly 1 B liters [4]. Where cellulosic ethanol will be produced in large quantities in the US remains to be seen [5,6]. Still, since feedstock transportation and handling costs comprise at least 50% of the cost of producing cellulosic ethanol [7], it will be cost effective for refineries to locate where required feedstocks are most abundant [8].

While crop residues comprise the most physically abundant feedstocks in the Cornbelt region [9], recent research regarding farmer willingness to market corn stover questions the total amount of stover that may ultimately be made available to a biomass market. It is possible that crop residue supplies will be constrained by limited farmer interest in harvesting these residues largely because of concerns for the agronomic and environmental consequences of residue removal and perceived low profitability of the endeavor [10–12]. Additionally, while the growth potential for increased production of switchgrass (particularly in terms of biomass yield) is very strong in corn-dominated regions (e.g., [13,14]), there are questions about the availability of land (particularly USDA Conservation Reserve Program [CRP] land) to be used for such a purpose [15,16]. At this point in time, with regard to crop residues and dedicated grass systems, "buy in" by farmers appears lacking [11,17]. All in all, it is unlikely that a single biomass feedstock will best suit all the needs of an evolving biomass energy market in the US Cornbelt region; as such, a portfolio approach to bioenergy feedstock production is needed [18]. Thus, the potential role of all regional feedstocks, even those that are niche oriented, should be assessed for viability – specifically the potential role of woody biomass needs to be examined more carefully.

Because of the physical abundance of assumed low-cost cellulosic feedstock from crop residues mentioned above, the potential for woody biomass as an energy input has not been adequately considered in the US Cornbelt. Yet, woody biomass is, in terms of bio-processing capabilities (e.g., the inherent energy capacity of wood combined with existing conversion technologies), a viable feedstock that can contribute to a spectrum of energy systems including conversion of low-quality wood into ethanol and other bio-chemicals, co-firing at coal-burning power plants that generate electricity, and thermal energy in industrial applications replacing natural gas [19–22]. Not only can wood be used to produce multiple energy outputs, woody biomass has several distinct ecological, social, and technological advantages that recommend it for consideration as a biofuel feedstock.

There is little debate about the potential of woody biomass from an energy balance stand-point as woody biomass offers very high energy output:input ratios of upwards of 55:1 [20,23]. In addition, Adler et al. [24] found that ethanol derived from hybrid poplar (combined with switchgrass) resulted in a 115% reduction in GHG emissions – this GHG reduction being a critical component of the 2007 Renewable Fuel Standard requirements of cellulosic based fuels. Woody biomass also possesses a number of other key logistical bio-feedstock benefits. For example woody systems:

- Can be scheduled for harvest across regional feedstock supply-sheds [25];
- Have inherent storage advantages that other cellulosic materials do not (e.g., materials can be stored "on the stump" or easily in the field) [26];
- Often have joint-production cost-sharing benefits particularly with forest and mill residues [27];
- Limited fuel-end concerns as combusting wood fuel does not appreciably contribute to acid rain pollution through sulfur emissions [28]; And,
- Are unlikely to compete with food or feed system markets [29] – the decoupling of feedstocks from food systems has been identified as a key to the sustainability of biofuels [30].

In addition to renewable fuel benefits, woody systems contribute to a whole host of potential societal benefits in the form of ecosystem services. For example woody systems:

- Can provide critical habitat and/or travel corridors for a diverse array of species [31], even in highly managed plantations [32];
- Can help stabilize soils and maintain soil quality [22,33];
- Efficiently cycle water and nutrients [22,33];
- Create long-term, below-ground reservoirs for carbon sequestration (in both natural or plantation systems) [34];
- May be ideal for restoring highly degraded lands and for bioremediation treatments [35,36].

Because of these ecosystem benefits there are specific concerns regarding the management of woody systems for biomass. Environmental impacts of woody biomass harvest and removal are of particular concern in the US Cornbelt in part because of the relative scarcity of forested ecosystems within this region: e.g., forest cover over the whole Central Cornbelt region has been estimated at ~24% and is already highly fragmented [37]. Additionally, these existing woodlands are often found on agriculturally marginal, unproductive and, in many cases, highly erodible lands.

Before specific questions can be answered about whether or not woody materials in the US Cornbelt comprise a viable niche feedstock in terms of volumetrically and environmentally sustainable woody biomass harvests, an assessment of the theoretical (estimate of existing biomass) and technical (estimate of biomass accessibility and availability given constraints in the supply system) biomass potentials is required.

The availability of any feedstock to a biomass market is a function of various ecological, agronomic, economic, and

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social factors. In the case of woody biomass, assessment of the upper-bound supply starts with the total physical amount of standing or otherwise existing biomass in any given year. Woody biomass that enters bioenergy markets in the US Cornbelt will largely take three forms [2,38]:

1) Standing biomass harvested and sold wholly to a bioenergy end-user – such biomass may be acquired from timber improvement thinning operations, harvests of small-diameter trees directly in natural forests, and from harvests of short-rotation plantations;
2) Logging residues remaining from logging operations where the bulk of the biomass has an end-use other than bioenergy; and
3) Primary and secondary wood industry residues (e.g., sawdust, end boards, cull logs/lumber, bark).

To a lesser degree, urban wood waste either from public and private tree systems (e.g., due to storm damage, pest/pathogen management, pruning, utility maintenance) or the woody component of the solid waste stream may make important contributions as well [3,39]. In particular, sanitation removals of ash (*Fraxinus* spp.) from urban areas due to the Emerald Ash Borer may become an important issue in woody biomass utilization throughout all of the US Midwest [40,41].

The subsequent availability of each form to a defined market is a function of several unique, dynamic, and regionally variable technological, environmental, infrastructural, economic, and social factors. Key factors include: aggregate regional forest resource base; spatial variability of the resource and accessibility; available infrastructure to harvest, process, and transport woody materials; land ownership structure and varying owner land-use goals; overall social acceptance of biomass management, regional ecological issues; and regional competition for woody materials [38,42]. Taken together these factors ultimately work to constrain and therefore scale the amount of biomass available for biofuel production.

Given the complexity of supply-related constraints a good starting point in examining the ability of US Cornbelt landscapes to provide woody feedstocks, we designed an exploratory analysis asking: (1) what is the current level of existing woody biomass and in what form does it exist; (2) where is this biomass located; and (3) what is the baseline potential for short-rotation woody biomass cropping systems? In an effort to answer these basic questions, we conducted an assessment of the woody biomass production and supply capabilities for a broad corridor along the Mississippi River in that is dominated by rowcrop agriculture. We focused on both the Midwest Driftless Area and the Central Dissected Till Plain ecoregions (Fig. 1), which comprise portions of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, and are in the central US Cornbelt. These areas were chosen because of substantial and on-going regional bioenergy development, substantial infrastructure to move both woody feedstock and biofuels, and because they possess relatively high forest cover for a region dominated by rowcrop agriculture [4,37,43]. Specifically, we assessed three sources of information regarding woody biomass resources in this aggregated region. Using existing forest and land-use inventories (e.g., [44–46]), we assessed (1) existing woody biomass in the forest; (2) potential land area that may be amenable to short-rotation woody biomass plantations; and (3) woody biomass within the existing primary forest industry. To further probe biomass scaling complexity within the primary wood industry, we also developed and implemented a forest industry survey with operators of large primary wood-using facilities (i.e., sawmills, veneer mills).

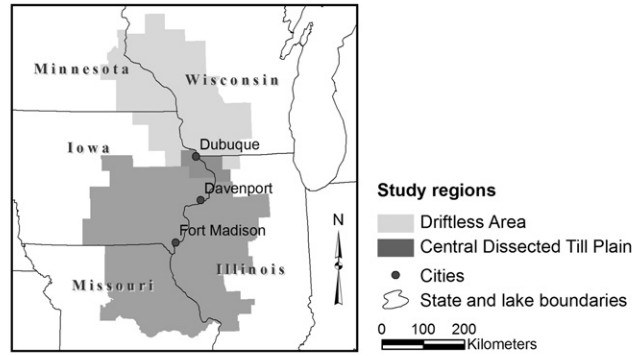

Fig. 1 – Study region delineating the Midwest Driftless Area and Central Dissected Till Plain. 3 Three Iowa cities located along the Mississippi River are included for geographical context.

2. Materials and methods

2.1. *Study area*

The Driftless Area (or Paleozoic Plateau) spans about 8.5 million ha (20.9 million ac) in southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois of the US Midwest. While rowcrops dominate bluff tops and valleys in this topographically dissected landscape, forests cover the hillsides and comprise ~26% of the region. The portion of the Central Dissected Till Plains we considered includes southeast Iowa, northeast Missouri, and western Illinois, and is just less than 14.7 million ha (36.2 million ac) 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 marginal for growing rowcrops [47]. Both areas possess an active sawlog and veneer timber industry.

2.2. *Data acquisition*

We used two key sets of secondary data as well as generated important primary data for this analysis. First, we derived data on total wood volume, annual net growth, and annual removals within natural forests from nationally available forest inventory and analysis data developed and maintained by the US Forest Service [44]. In cases where the available data was not expressed as dry weights, we converted available cubic foot volumes using conversion estimates from the published literature [48].

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Secondly, information on wood residues produced as a byproduct within the established wood-using industry was gathered in two ways. We used nationally-available timber product output data developed and maintained by the US Forest Service to estimate annual removals, logging residues and mill residues [45,49] and conducted a telephone survey with owners/managers of sawmills within our study areas. Our 2007 survey was designed to assess the production of biomass residue at area 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), and the overall fate of residue (e.g., internal usage, market, otherwise disposed). Mill owners were also asked about 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 survey sample consisted of 86 sawmills located within our study region in 2007 who were reported to annually produce over 1 MMBF of varied output as listed in the most recent respective state extension and/or department of natural resources databases. Eleven southeastern Minnesota counties, 34 northwestern Illinois counties, 24 northeastern Missouri counties, and 24 southwestern Wisconsin counties were included in our sample; in Iowa, because the sawmill industry is considerably smaller than that of the other states, our sample included all sawmills that have kilns in 39 counties in the eastern portion of the state—these being the largest mills in operation (Jesse Randall, Iowa State University Extension, pers. comm. 2007). Fifteen of the 86 mills were classified as ineligible (10 verified as out-of-business, three Amish sawmills with no telephone, and two non-sawmills that made products from the byproducts of sawmills). This resulted in an eligible sample of 71 sawmills. Interviews were completed with 43 of the sawmills, for an overall response rate of 60.6%. Because a full census of all the mills in the designated regions was not conducted, the data only represent the reporting mills—therefore reported "totals" may be viewed as lower bound parameters for these areas.

3. Results and discussion

3.1. *Biomass in natural forests: amount and composition*

The latest USDA Forest Service estimate for the state indicated 2.2 million ha (5.4 million ac) of timberland in each of the Driftless Area and Central Dissected Till Plain regions, up from 2.1 (5.2) and 1.8 (4.5) respectively around 1990. 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 forest land conversion, which was shown by these data. Expansion of urban areas and new land clearing for agriculture may reduce these recent gains in forest land in the future [50].

Eighty-seven percent of these timberlands were owned by non-industrial private forest, or family, ownership [44]. States and counties/municipalities comprised the majority of remaining ownerships, with approximately 5% of the land base each [44]. Historically, 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 [51]. Although we lacked 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 15.4 ha (38 ac) [51].

The overall amount of woody biomass was 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 posed the largest woody biomass resource (Fig. 2a); however, substantial resources also existed within northeastern Iowa. Although the regions support high tree diversity, most of the biomass was contained within a few species, including species of maple (*Acer* spp.), shagbark hickory (*Carya ovata*), oak (*Quercus* spp.), and American elm (*Ulmus americana*). Silver maple (*Acer saccharinum*) comprised much of the biomass along the Mississippi River.

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, which outcompetes most other timber sectors on stumpage prices for sawlogs. Therefore non-sawlog species are of importance for a woody biomass market.

The spatial pattern of the non-sawlog woody biomass resource was similar to that of total live woody biomass, but comprised a much greater proportion of the biomass in the northern portion of the Central Dissected Till Plain (Fig. 2b). Non-sawlog biomass was also highly variable by species, with high proportions of species unsuitable or less desirable for sawlog production. Species in which non-sawlog material generally made up >75% of the total biomass across regions included boxelder (*Acer negundo*), red maple (*Acer rubrum*), paper birch (*Betula papyrifera*), bitternut hickory (*Carya cordiformis*), honeylocust (*Gleditsia triacanthos*), butternut (*Juglans cineria*), osage-orange (*Maclura pomifera*), red mulberry (*Morus rubra*), Eastern hop hornbeam (*Ostrya virginiana*), black locust (*Robinia pseudoacacia*), black willow (*Salix nigra*), American elm, and 'other hardwoods' (a combination of American hornbeam [*Carpinus caroliniana*], ailanthus [*Ailanthus altissima*], pawpaw [*Asimina triloba*], sassafras [*Sassafras albidum*], rock elm [*Ulmus thomasii*], etc.). Species in which non-sawlog material comprises 55–75% of the total biomass across regions included Eastern red cedar (*Juniperus virginiana*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), hickory species (bitternut, shagbark, shellbark [*Carya laciniosa*], and mockernut [*Carya tomentosa*]), hackberry (*Celtis occidentalis*), black ash (*Fraxinus nigra*), quaking aspen (*Populus tremuloides*), black cherry (*Prunus serotina*), chinkapin oak (*Quercus muehlenbergii*), post oak (*Quercus stellata*), and slippery elm (*Ulmus rubra*). Several species,

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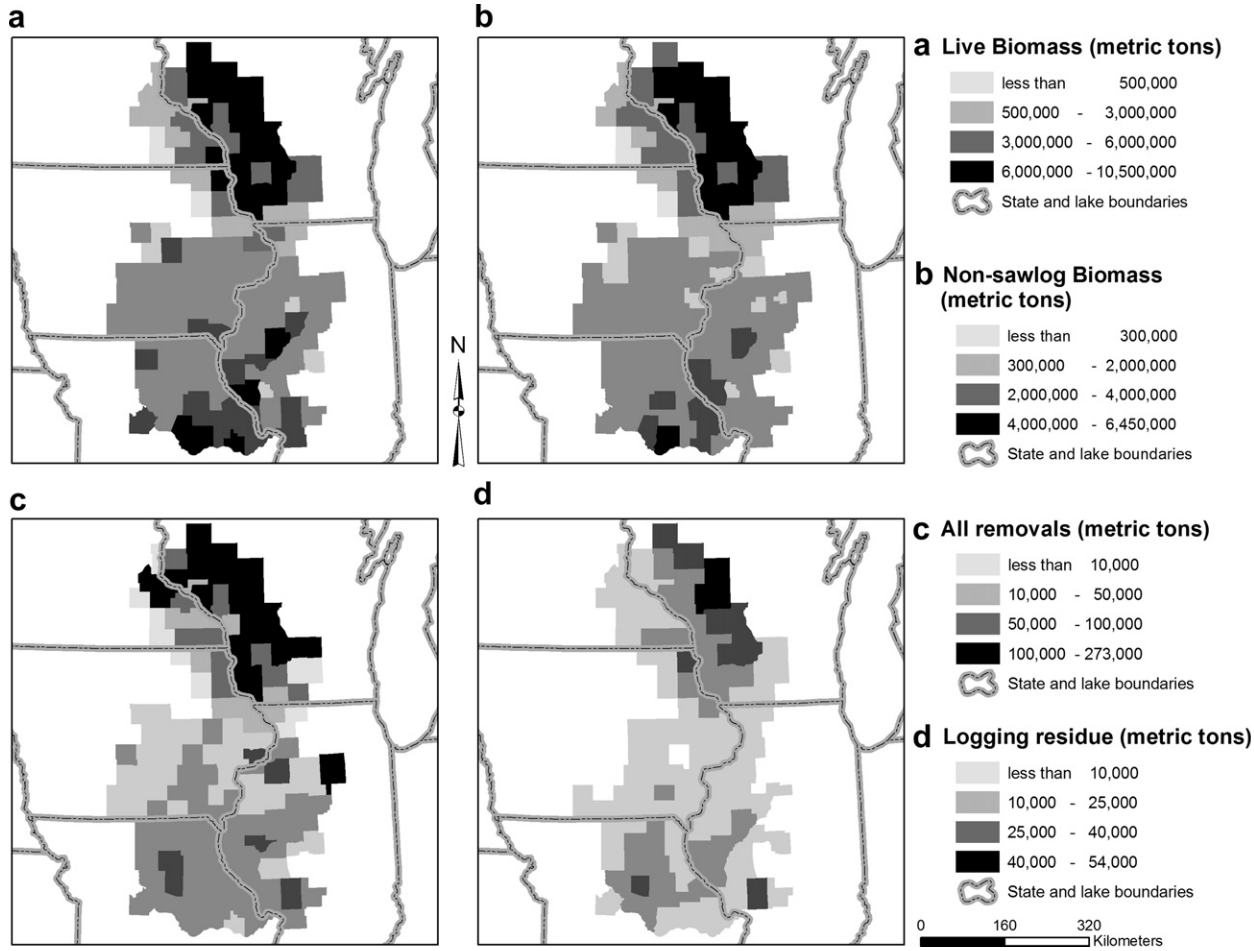

Fig. 2 – a) Total live biomass, b) total non-sawlog live biomass, c) total removals, d) total 8 logging residues by county.

including white ash (*Fraxinus americana*), green ash (*Fraxinus pennsylvanica*), black ash, American elm, and butternut, are threatened by insect or disease problems that might be reduced by carefully applied sanitation harvests.

3.2. *Short-rotation woody biomass*

Recent non-US Cornbelt regional assessments of woody biomass potential discuss the importance of short-rotation woody biomass “energy plantations” in terms of providing woody feedstock systems with increased supply reliability and efficiency [52,53]. Throughout the US Cornbelt, marginal farmlands and/or farmland enrolled in CRP comprise the most likely locations for siting woody biomass plantations [52,54]. As a coarse estimate of the extent of marginal farmlands in the region, we summarized the number of acres actively enrolled CRP [46]. The Central Dissected Till Plain poses the highest density of CRP acres (Fig. 3), with over 809,000 ha (2 million acr) enrolled at present. The density of CRP acres are also high in some portions of the Driftless Area, however, with 353,000 ha (871,000 ac) enrolled across these counties. It should be noted however that CRP acres throughout the whole Cornbelt region have contracted significantly in recent years [16].

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 recent Cornbelt region woody cropping system data [54–56], the utilization of aspen on the steeper ground and selected bottomlands, and cottonwood on the areas prone to flooding, once an 8-year rotation is established an average annual production of 5 dry tons/acre should be achievable. Given these assumptions, 1 million dry tons of biomass could be produced annually in the Central Dissected Till Plain, and over 217,000 dry tons in the Driftless area.

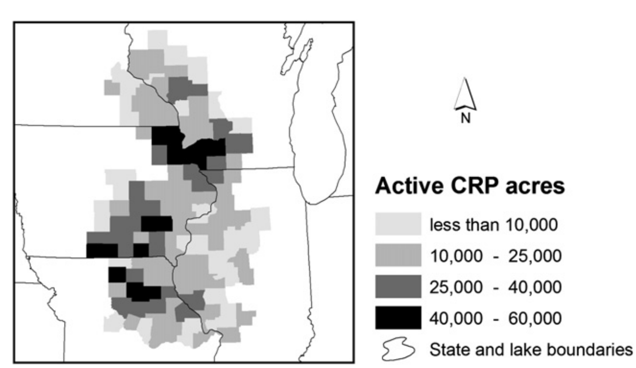

Fig. 3 – Active Conservation Reserve Program acres (as of October 2007).

3.3. Biomass in the existing timber industry

Surveys of the existing timber industry and interviews with professional foresters suggested that only a small portion of the woody resource in these regions is being accessed at present. Based on US Forest Service Timber Product Output data [45], total harvesting activity has accessed only a small portion of the total wood biomass resource available and has been fairly stable over time. However, harvests in the Driftless Area have been somewhat higher, reflecting changes in the industry that have allowed the use of smaller diameter material, and slightly lower in the Central Dissected Till Plain, due to the loss of a large International Paper pulp mill.

The Driftless Area experienced the highest level of harvesting activity of the three regions, with 1.7% of the total live biomass harvested annually (Fig. 2c); in other words, these forests have been on a 59 year rotation. Harvesting levels were lower in the Central Dissected Till Plain (0.9% harvested annually or 111 year rotation).

Of the overall biomass harvested annually, the proportion transferred into a measurable product was variable by region with a higher percentage of harvested material in the Driftless Area ending up as relatively high-value saw timber product. Forty-seven percent of the annually harvested biomass in the Driftless Area was transferred to product; high-value veneer and sawlogs, while the remaining 53% of harvested material included either low-value products (26%; e.g., pulpwood, composites, posts, poles, pilings, and fuel wood), logging residues (20%), or.mill residues (6%). In the Central Dissected Till Plains 34% of harvested material ended up as high-value product with the remaining 66% was comprised of logging and mill residue (43%) and assorted low-value products (23%). Whereas the bioenergy industry is unlikely to compete with the high prices sawlogs receive, residue and low-value products may offer economically viable opportunities. In terms of species mix, much of the red pine, aspen, cottonwood (*Populus deltoides*), elm, and other softwoods and hardwoods comprised the majority of low-value timber product volume and could most readily be captured by the bioenergy market. A substantial portion of the harvested biomass in the Driftless Area (17.8%) and the Central Dissected Till Plain (26.1%) remained on site as logging residue because markets for the material are currently small to non-existent (Fig. 2d). Yet, as harvests have increased over time (Fig. 4a), the overall biomass that comprised logging residues has declined (Fig. 4b), suggesting changes that allow the collection and transport of a wider array of woody material have already occurred in the regional industry.

See Table 1 below for a full summary of natural forest biomass data for the study region presented by ecoregion and on a state by state basis.

3.4. Residual biomass availability from regional sawmills

Saw timber and veneer mills are scattered across the study region. Interviews with mill owners and/or managers in the regions suggested that only a portion of mill residues would be potentially available for bioenergy production. Due to high energy costs, most sizeable mills have added sawdust consuming kilns to their facilities, which allow on-site 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 suggested that about 82% of the residue generated could be available within a competitive market. Data also suggested variability between states, with Illinois, Iowa, Minnesota, Missouri, and Wisconsin having potential residue availability rates of 60%, 71%, 95%, 70%, and 95%, respectively. Residues sold were shipped on average 272 km (169 mi) from the mill site. Conversely, wood chips were trucked over distances up to 322 km (200 mi)), sold at cost, and could be readily available in the region as a bioenergy feedstock.

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. In addition to total product output, 29 sawmills reported the amount of residue they generated in 2006. Across these 29 mills, just over 172,000 dry metric tons (190,000 dry tons, US short) of residue were generated (Table 2). The Lumber Recovery Percentage (LRP) was 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 LRPs [57,58].

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 surveyed Illinois and Iowa sawmills ($n = 19$) used 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 (Table 2). The mills reporting in Missouri ($n = 8$) and Wisconsin ($n = 8$) internally used 7% and 4%, respectively. The Minnesota mills ($n = 6$) claimed to use less than 1%. Across the whole study region, 78% of the residue material was sold in various regional residue markets. Minnesota and Wisconsin mills sold the vast majority of their materials (99% and 94% respectively). Current biomass markets, largely in the

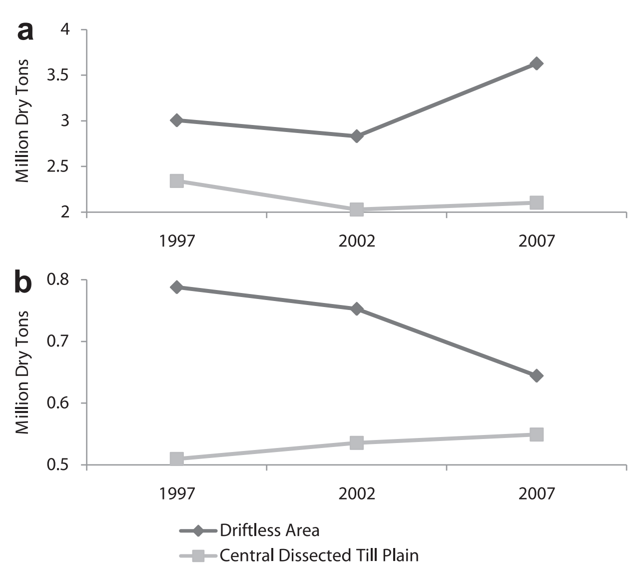

Fig. 4 – Total a) harvest volume and b) logging residue over time (1997–2007).

Table 1 – Various measures of woody biomass in millions of dry metric tonnes (Dry Mg) by state within study region – see Fig. 1. (Data: USFS 2007a; USDA 20ed07b).

Biomass category	Driftless area	Central dissected till plain	SE MN	SW WI	W Il	E IA	NE MO
Total live biomass (Million/Dry Mg)	219.48	235.59	27.66	160.99	84.41	80.58	90.49
Non-sawlog biomass [a] (Million/Dry Mg)	122.05	104.42	16.99	92.03	32.84	37.56	42.47
Annual net growth [b] (Million/Dry Mg; all species)	3.85	5.31	0.81	2.43	1.95	1.84	1.79
Annual net growth (Million/Dry Mg; non-sawlog species) [c]	1.06	1.43	0.22	0.76	0.54	0.49	0.44
Total harvests (Million/Dry Mg)	3.69	2.12	0.64	2.77	0.91	0.65	0.75
Logging residue [d]	0.65	0.56	0.07	0.49	0.19	0.18	0.25

a Live biomass ≤ 8 inches in diameter.
b 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.
c Dominant Non-saw timber species 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.
d Logging residues are "the unused portions of growing-stock and non-growing-stock trees cut or killed by logging and left in the woods"[49].

form of wood chips, has supported fairly long material transportation distances. Across all states, the average shipping distance for sawmill residue was 272 km (169 mi). Missouri mills averaged the longest distance at 370 km (230 mi), and Wisconsin the shortest at 193 km (120 mi).

Assuming that residue used internally for energy production is unavailable to an external market (biomass or other) but residue in the other categories is, these data suggest that overall about 82% of the residue generated by sawmills in the entire region was physically available for a competitive biomass market at the time of the survey (Table 3). Based on these results, the lower bound level of residue that would have been competitively available to a biomass market in 2006 was approximately 107,000 dry metric tons (118,000 dry tons US Short).

While at least 107,000 dry metric tons of sawmill residue was potentially available for sale in a biomass market, the actual availability scales with gate prices. Based on estimates provided by reporting mills ($n = 26$), availability at various prices tracked closely with the average reported break-even sale price (at the mill gate) for residues (Fig. 5). Minnesota had the highest average break-even price at $35.56 per dry metric ton ($39.20/dry ton US Short) and Missouri had the lowest at $17.69 per dry metric ton ($19.50/dry ton US Short). The regional average was $30.81 per dry metric ton ($30.81/dry ton

Table 2 – Percentage breakdown of residue type and current residue usage for each state ($n = 41$).

State	Residue usage	Bark	Coarse residue[a]	Fine residue[b]
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

a Chips, slabs, edgings, trims, cores, etc.
b Planer and lathe shavings & sawdust.

Table 3 – Percentage and volume of sawmill residue that is potentially available for sale in a biomass market by state and across the region ($n = 41$). These are lower bound annual estimates.

Region	Residue produced (Dry Mg)	Residue available (Dry Mg)	Residue potentially available for sale (%)
Eastern Iowa	46,482	33,002	71
NE Missouri	40,551	2839	70
SW Wisconsin	34,768	33,377	96
NE Illinois	32,704	19,622	60
SE Minnesota	18,089	18,089	100
Total	172,595	106,930	82

US Short). It needs to be recognized however, that physical and economic availability of these materials is contingent upon a number of dynamic factors. Recent housing market downturns caused the US dimensional lumber industry to reduce output; this coupled with regional sawmill industry contraction (or consolidation) in turn created significant regional shortages for residue materials (e.g., [59,60]). Furthermore increased demand from market expansion of residue based industries (e.g., wood pellets) and steady improvements in sawmill technology that increases lumber recovery rates have been noted to effectively reduce residue availability for bioenergy use [61]. Concomitant with variable physical availability and the increase in regional competition for feedstock typically comes a rise in regional gate prices as well as a general increase in price volatility [28,62].

In response to open-ended questions regarding concerns or financial issues that might impact their willingness to sell mill residue to an ethanol refinery, about 38% of the respondents across all five states stated that they were generally concerned about the “sustainability” of the biomass market. Collectively, these sawmill operators defined sustainable biomass market as one backed by a “financially stable” local/regional refinery that (in order of importance): 1) “pays on-time” as accorded by a 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 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). 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 concern (from 12% of the respondents) about potential transaction costs associated with “dropping current customers.” These transaction costs relate to: 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). Mill operators also suggested that if the ethanol industry was going to look toward woody feedstock resources then it should invest in local and regional forest management.

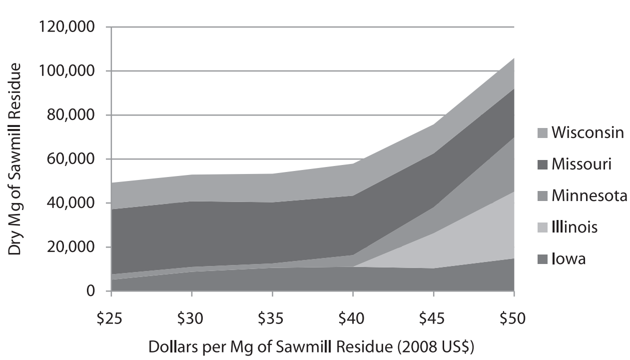

Fig. 5 – Total residue available at various market prices ($/Mg) by state ($n = 26$).

In terms of the factors that would increase a mills’ interest in selling residues to a refinery, just over 42% of the 43 mills responding stated that only financial issues (e.g. profitability and consistency in the market) matter. 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 mentioned 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 mentioned 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.

4. Conclusions

Based on this exploratory analysis our study region appears to physically possess enough woody biomass to support limited cellulosic ethanol production at present. On an annual basis, taking into account only the annual net growth of non-sawlog species the Driftless Area currently produces 3.14 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 3.94 times the required material. Throughout the entire region there would be an additional 107,000 dry Mg from easily transportable sawmill residues. Very likely, the key issues to overcome in these areas at present are inefficiencies in the access and transport of available material.

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. Before plantation wood can be available in quantity however, several things must happen. More rural land owners 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 (e.g., jointly producing biomass and various ecosystem services) and be willing to help cost share establishment costs to encourage entry into the production of

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these woody crops. Interested bio-refineries will need to work out contract arrangements that provide some annual income for land owners in between harvests while still providing incentives for good management that will optimize plantation yields. To this end, the most recent US Farm Bill created provisions for the Biomass Crop Assistance Program which provides cost share and land-use payments for private forest land owners to make available materials from both natural and plantation systems and partnering producers directly with area biomass conversion facilities via long term (10 year) contracts that contain price support provisions [63].

While the information provided with this examination shows strong possibilities of woody biomass being a niche feedstock in the US Cornbelt many complexities still remain to be examined. Beyond the physical abundance of woody materials that do not otherwise have higher end-use value (e.g., as wood products), the subsequent availability of woody biomass to a defined bioenergy market is ultimately a function of several unique dynamic and regionally variable technological, environmental, infrastructural, economic, and social factors. Taken together these factors ultimately work to constrain and therefore scale the amount of biomass available for biofuel production [38,42]. For example, the market availability of woody biomass in heavily forested regions tends to be enhanced by well established and diversified forest industries (from extraction through to processing) and therefore the region is positioned with high equipment capacity, trained labor pools, and specialized transportation systems [64]. States (or portions of states) that do not have significant forested acres typically have less well defined infrastructures and would need time to draw capital investment [65]. Social factors, in the form of typical landowner management goals, overall public perceptions of forest land biomass management, land ownership and tenure patterns, and policy incentives, may be supportive or in opposition. The amount of forest land that is actively managed and reinforced via a management plan varies significantly from region to region and is associated with overall landowner goals and parcel size [66,67]. Midwestern woodlot owners also tend to have land-use goals other than profitability—goals such as recreation, aesthetics, wildlife, hunting, and legacy [63,68]. Previous research regarding the US Midwest (e.g., [51]) has indicated that woodland owner interests in and values regarding the relative importance of economic gains over aesthetics and passive land use (e.g., bird watching, recreation) are scale dependent with economic goals becoming dominant only as forest parcels increase to fairly large sizes (>700 contiguous acres). One likely important barrier is the size of the average private woodlot in the US Cornbelt—as noted earlier, the national average for private forest holdings is 15.4 ha (38 ac); in Iowa average woodlot size stands at roughly 4 ha (≈10 acres) and has shown a constant decline over the years as land is divided during intergeneration transfers or “lost” during suburban sprawl (Paul Tauke, IDNR Forestry Bureau Chief, pers comm. 2009). Because of this scale related issue cross-property boundary cooperation will likely be required to coordinate landowner actions regarding biomass harvesting across aggregated land areas [69,70] and to facilitate scheduled biomass pick-up and transportation so as to minimize transportation costs [60].

Environmental impacts of biomass harvest and removal are of particular concern (privately and publicly) in the US Cornbelt in part because of the relative scarcity of forested ecosystems. Those woodlands that do exist are often found on agriculturally marginal, unproductive and, in many cases, highly erodible lands. The amount of biomass that can be sustainably removed from a landscape is dependent upon topography (impacting accessibility and post-removal environmental impacts such as erosion) and the ecological needs/constraints of a particular area (e.g., as related to nutrient cycling, water quality, carbon sequestration, wildlife habitat). Largely because of ecological concerns, many states including three in our study region (e.g. Minnesota, Wisconsin, Missouri, Pennsylvania, and North Carolina) have developed biomass harvest standards designed to maximize the amount of biomass that can sustainably be harvested over the long run without negatively affecting the ecological quality of the forest site [71]. By and large, these standards promote silvicultural practices designed to: a) maintain soil productivity by limiting disturbance in forest floors and minimizing erosion; b) maintain water quality by minimizing erosion and strictly maintaining buffers around riparian areas; and c) maintain habitat for biodiversity by retaining critical horizontal and vertical structure [72].

Because woody biomass appears to be abundant enough in the US Cornbelt to be considered a legitimate cellulosic feedstock particularly in a multiple-feedstock portfolio context, it will be critical that woody biomass management adhere to environmentally sound silvicultural systems [73]. The ecological state of US Cornbelt forests stand to gain from a developed market for woody biomass as proper woodland management to harvest trees, preserve wildlife, and reduce risk from disease, pests, and invasive species has always involved harvesting the low-value trees that will by and large drive the woody biomass system 70]. Because woody biomass management is often consistent with other forest goals, opportunities for increased multi-objective forest management will also likely expand with regard to forest-based recreation, wildlife habitat improvement, and enhanced regeneration of vulnerable ecosystems such as Midwestern oak-hickory forests (Joe Herring, Iowa DNR, pers. comm., 2008). Ultimately, hundreds of thousands of private forest land owners in the US Cornbelt region stand to gain from a developed market for woody biomass in terms of income generation and increased opportunities for multi-objective forest management.

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