SUSTAINABLE BIOENERGY PRODUCTION FROM MISSOURI'S OZARK FORESTS

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Abstract.—The main source of wood fiber for energy resides in Missouri's forests. Alternative bioenergy systems that can use forest thinning residues are electrical energy, thermal energy, and liquid bio-fuel. By applying a thinning rule and accounting for wood fiber that could go into higher value wood products to all live biomass data extracted from the U.S. Forest Service Forest Inventory and Analysis database for a 44-county area in southern Missouri, we determined that a "typical" Ozark upland hardwood acre would conservatively yield 9.3 green tons as a result of a forest thinning operation. This per-acre yield was then spatially distributed across privately owned land across the selected area based upon the deciduous cover layer in the Missouri Resource Analysis Project database. Based on the infeed requirements of three wood-to-energy enterprises, our spatial analysis tool revealed that to support a sustainable re-entry interval of 20 years, thinning operations would need to be conducted on one out of every 67 privately owned acres within a 45-mile radius of the bioenergy plant.

INTRODUCTION

A potential feedstock for meeting some of our nation's renewable energy goals is wood: wood waste from sawmills and secondary manufacturing plants (e.g., flooring plants and pallet mills); urban wood waste from utility rights-of-way and storm debris clean-up operations; and wood from thinning our overcrowded forests. Wood residuals from sawmills and secondary manufacturing plants (e.g., sawdust, slabs and edgings, chips) are no longer considered waste as they are going into everything from mulch to composite deck material. As a result, very little of this material is available for any large-scale wood-to-energy enterprise. Urban wood waste seems like a reasonable alternative to mill residues for producing energy, but the desirable fiber of the tree trunk is usually commingled with bark, smaller branches, and leaves. These latter components have very low energy values due to their high moisture content and they also generate larger amounts of ash.

The main source of wood fiber for energy lies in Missouri's forests. The good news is we have a lot of it. Missouri is approximately 45 million acres in size, one-third of which is forested (Moser and others 2007). The challenges are the economic viability and the biological sustainability of a wood-to-energy enterprise.

OBJECTIVE

Our objective was to determine how many forested acres would be required to supply three different types of wood-to-energy systems based upon either existing or accepted technologies given the constraints of ownership patterns and the stipulation that the wood must come from sustainable forest thinning operations.

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WOOD-BASED BIOENERGY SYSTEMS

Potential wood-based bioenergy systems include: (1) electrical energy; (2) thermal energy for heating/cooling institutional buildings or large multi-building facilities; and (3) liquid fuels (e.g., bio-oil or ethanol). Rather than board feet, cords, or green tons, the proper currency for energy systems is British Thermal Units (BTUs). One BTU is the amount of energy required to raise the temperature of 1 pound of water by 1 °Fahrenheit. Some common conversion factors to remember when converting from green tons of wood to BTUs are: (1) green wood has a moisture content of 50 percent; (2) there are 8,600 BTU per pound of dry woody biomass; and (3) there are 2,000 pounds per ton.

Electrical Energy

Depending upon time of day and time of year the load factor on the power grid can vary tremendously, but on average, 1 megawatt (MW) can meet the energy needs of around 800 homes. Approximately 3.41 million BTUs are required to produce 1 MW of electrical energy for 1 hour. Unfortunately, the technology for direct-firing power plants currently in operation is based upon coal and natural gas, both of which have higher per-unit BTU energy content than wood. As a result, burning wood in these plants captures only about 37 percent of wood's energy potential. It's like heating your home using an open fireplace.

Even though generation of electricity is not the most prudent use of wood for energy, several biopower plants are in operation today, including in Burlington, VT (50 MW), Craven County, NC (40 MW), and St. Paul, MN, (25 MW). Given the above constraints, a 25-MW power plant would require 597,432 million BTUs annually (3.41 million BTUs/hr x 24 hr/day x 365 days/yr) or 187,878 green tons of wood.

Thermal Energy

One feature of the St. Paul, MN, biopower plant is that the utility uses the low-pressure steam exiting the electrical generating turbines to heat and cool the central downtown area. This process is identical to that at Northwest Missouri State University in Maryville, MO, which has been generating low-pressure steam from wood fiber to heat and cool 2,000,000 sq. ft. of campus buildings since 1982. Sixty-six percent of the required 250,000 million BTUs come from wood chips, 10 percent from palletized, clean, community waste paper, and the remainder from natural gas. The wood chips vary from 10 to 40 percent moisture, averaging just over 30 percent. These chips are acquired from the waste generated by the forest products industry in the region served by the University. Paper pellets were introduced in 1992.

The 1980-81 Northwest Missouri heating/cooling plant capital cost valued in 2007 dollars is $7.8 million. The university has paid an average of $26.50 per ton for wood chips delivered to the plant for the last three years of record. The resulting variable cost per million BTUs of steam provided is $4 to $5 compared to nearly $11 for natural gas. Northwest Missouri has saved $475,000 per year for the last 23 years. A thermal plant of similar design to the Northwest facility would require 29,000 green tons of wood annually.

Liquid Bio-fuels

This wood-to-energy technology is still much in its infancy and is probably 2 to 5 years away from maturing into commercial-sized production facilities. As opposed to the enzymatic process of producing ethanol from corn, bio-fuels derived from wood will be driven primarily by gasification technology. Sounds high-tech, doesn't it? But anyone who has ever been involved with making charcoal is already familiar with this process. The old charcoal kiln has been replaced with a bio-reactor where temperature and atmosphere within the reactor can be tightly controlled. And instead of a focus on the lumpy, carbon residue (charcoal) left at the end of the process, the focus is now on capturing the volatile compounds that are driven out of the wood during the process. Depending upon the specific technology applied, the end product can be combustible gases, a mixture of alcohols (including ethanol), or a heavy bio-oil.

For the purpose of our discussion here, we will focus on a unique technology developed by Bioengineering Resources Inc. (BRI) of Fayetteville, AR, that combines gasification with an enzymatic reaction downstream from the gasification step to produce 6 to 8 million gallons of ethanol. This system also produces 5 to 6 MW of power. These modular units require 200,000 tons of green biomass annually.

Before conducting preliminary economic analyses on the construction and operation of these bioenergy plants, we must determine proper regional cost and revenue figures for input into the models. To obtain these inputs, we need to know how the available woody biomass is spatially distributed across the state in order to identify regions that will be able to support the facility.

WOODY BIOMASS AVAILABILITY

More than 350,000 private citizens own roughly 83 percent (12.1 million acres) of the state's 14.6 million acres of forest land (Moser and others 2007). The remaining 27 percent is owned by private businesses (10 percent) and public agencies (17 percent). The wood fiber on these lands is not considered available for bioenergy because the trees are either destined for other uses or virtually "locked-up" in regulatory statutes. Based upon personal surveys, the general consensus among forestry professionals in the state is that 90 to 95 percent of the lands owned by private individuals are not being actively managed and that only an additional 25 percent would be captured with some type of wood-to-energy market incentive.

Total tree biomass is the total weight of all-live aboveground components of forest trees. In Missouri, approximately 72 percent of a tree's total biomass is found in the stem and the remaining 28 percent is in the stump, top, and limbs (Moser and others 2007). We chose to measure biomass for bioenergy in green tons rather than BTUs because the forest products industry is more familiar with weight measure.

The first step in developing our woody biomass spatial analysis tool was to determine what the "typical" Ozark acre might yield as a result of a forest thinning operation. We took a conservative route for two reasons. First, we wanted a silvicultural prescription that would have minimal (if any) adverse effect on the existing forest products industry in the state. Plus, we wanted to leave the landowner with a residual forest capable of producing high-value timber at some point in the future. Second, we wanted to paint a solid picture of the wood supply for potential investment capital.

This "typical" acre contains some caveats. For example, it would be expected that an acre of ground with a south- or west-facing aspect would be lower in site quality and therefore yield less than an acre found on a higher quality, north- or east-facing aspect. Also, while an even-age silvicultural prescription would be the norm, local site conditions and individual ownership objectives would influence the actual biomass yields. For the first iteration of this tool, we assumed that the thinning operation would leave a residual hardwood forest stand just above the suggested basal area of 65 square feet per acre (Gingrich 1967).

We developed our acre of Ozark forest by extracting U.S. Forest Service Inventory and Analysis (FIA) data from the agency's online database and Forest Inventory MapMaker V3.0 (Miles 2001). The data were filtered based upon the following constraints:

1. All Missouri cCounties south and east of the I-44 corridor. This constraint yielded 1,800+ FIA plots and produced a seamless mosaic across county lines that otherwise would have resulted in disjoints between counties if based on a county-by-county query.
2. Land classified as "timberland": forest land not restricted from harvesting by statute, administrative regulation, or designation, and capable of growing trees at a rate of 20 ft^3 per acre per year at maximum annual increment.
3. Ownership classified as "private"; all public lands were excluded due to the uncertain nature of availability.
4. Hardwood species only; cedar, pine and mixed oak/pine were excluded due to potential biorefinery feedstock uniformity requirements.

The extracted data were stratified by diameter class and basal area (BA) class (Table 1). Gingrich (1967) found that 40 percent of the basal area could be removed from a stand that was 100-percent stocked without loss of total stand growth. Using this result as a recommendation for a maximum thinning rule, since 0-40 BA is understocked and the median of 41-80 BA is at the cut-off of a fully stocked upland hardwood stand, no thinning tonnages would be available from these acres.

We assume the median stocking level for the 80-120 BA is 100 ft^2 per acre. A 40-percent reduction by thinning would leave 60 ft^2 per acre, which would leave an under-stocked stand in most cases. To avoid this outcome, we reduced the thinning percentage to 30 percent. Because nearly all of our Ozark forest stands are beyond the point of canopy closure, we assumed that volume is linearly related to BA in stands of these diameter ranges in upland oaks. Since the 120+ BA class is open-ended, we chose to be conservative and set the average BA at 125 ft^2 per acre. We further chose a thinning target of 75 ft^2 per acre which reflects a 40-percent thinning and keeps all acres in the fully stocked class.

Then for each diameter class, we asked mill operators in the region for their opinion as to what percentage of the incoming wood could be utilized for higher-value wood products. Keep in mind that in Missouri, higher-value wood products include industrial blocking and pallets. We then totaled the amount of wood across all the diameter classes that would be potentially available for bioenergy and divided that figure by the total amount of private timberland as extracted from the FIA database to yield an average of 9.5 green tons per acre.

This quantity of available biomass was then spatially distributed over the same area of the Missouri Ozarks from which the FIA data were extracted based on the percentage of deciduous forest cover. This forest cover data layer was made available through the Missouri Resource Assessment Partnership (University of Missouri, Columbia, MO). The spatial distribution was conducted on a 30-m^2 pixel and then aggregated by square mile to frame the biomass estimate in a more familiar format.

Using ArcMap™ 9.2 (Environmental Systems Research Institute, Redlands, CA), constraints (exclusions) placed upon this spatial data layer were as follows: (1) Mark Twain National Forest land not being considered for harvest; (2) Ozark National Scenic Riverways; (3) state-owned forest land; (4) forest land managed by the Pioneer Forest; (5) incorporated areas; (6) road rights-of-way; (7) land whose slope exceeds 35 percent, and (8) 3-mile buffer around all major lakes.

Table 1.—Total all-live biomass (million green tons), by diameter class, that would be available in the 44-county area of southern Missouri from fully stocked basal area classes of 80-120 and 120+ ft^2 per acre and accounting for a portion of that biomass being diverted into wood products of higher value than bioenergy

Diameter class (inches)	Total all-live biomass (million green tons)					All-live biomass from forest thinning operations (million green tons)			Disposition of all-live biomass from thinning operations	Biomass available for bioenergy (million green tons)
	Basal area class									
	Total	0-40	41-80	81-120	120+	81-120	120+	Total		
1.0-2.9	13.96	0.56	4.98	6.48	1.93	2.27	0.77	3.04	leave as understory	0.00
3.0-4.9	26.41	0.61	7.22	13.54	5.05	4.74	2.02	6.76	leave as understory	0.00
5.0-6.9	37.70	1.18	12.44	18.47	5.60	6.46	2.24	8.70	100% biomass	8.71
7.0-8.9	50.84	1.32	16.33	25.50	7.69	8.92	3.08	12.00	100% biomass	12.00
9.0-10.9	59.58	1.42	17.47	30.50	10.18	10.68	4.07	14.75	100% biomass	14.75
11.0-12.9	63.75	1.10	17.34	32.24	13.10	11.28	5.25	16.53	40% biomass : 60% grade	6.61
13.0-14.9	57.33	0.91	14.26	29.41	12.75	10.30	5.10	15.40	40% biomass : 60% grade	6.16
15.0-16.9	44.13	0.45	8.64	22.97	12.07	8.04	4.83	12.87	25% biomass : 75% grade	3.22
17.0-18.9	30.68	0.44	5.30	15.76	9.17	5.52	3.67	9.19	25% biomass : 75% grade	2.30
19.0-20.9	23.65	0.56	3.09	11.79	8.21	4.13	3.28	7.41	25% biomass : 75% grade	1.85
21.0-22.9	12.31	0.34	1.31	6.85	3.81	2.40	1.52	3.92	25% biomass : 75% grade	0.98
23.0-24.9	8.01	0.68	1.87	2.85	3.23	1.00	1.29	2.29	25% biomass : 75% grade	0.57
25.0-26.9	3.95	0.07	0.62	1.26	2.00	0.44	0.80	1.24	25% biomass : 75% grade	0.31
27.0-28.9	2.43	0.00	0.38	0.75	1.30	0.26	0.52	0.78	25% biomass : 75% grade	0.20
29.0-30.9	1.70	0.20	0.20	0.57	0.73	0.20	0.29	0.49	25% biomass : 75% grade	0.12
31.0-32.9	9.17	0.00	0.00	0.78	0.14	0.27	0.06	0.33	25% biomass : 75% grade	0.08
33.0-34.9	1.62	0.00	0.00	0.30	1.32	0.12	0.53	0.63	25% biomass : 75% grade	0.16
35.0-36.9	0.64	0.00	0.00	0.28	0.36	0.10	0.14	0.24	25% biomass : 75% grade	0.06
37.0-38.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25% biomass : 75% grade	0.00
39.0-40.9	0.17	0.00	0.00	0.00	0.17	0.00	0.07	0.70	25% biomass : 75% grade	0.02
41.0+	0.48	0.00	0.00	0.00	0.48	0.00	0.19	0.19	25% biomass : 75% grade	0.05
Total	440.27	9.20	111.45	220.31	99.31	77.13	39.72	116.85		58.14

This data layer was then used to create a "moving window" with a 25-mile radius along major highways that would estimate the amount of available woody biomass within that area (Fig. 1). From this analysis we have identified three communities in southern Missouri capable of supporting a sustainable wood-to-energy enterprise: Fredericktown, Cuba, and Thayer. For the purpose of this paper we will limit our discussion to Fredericktown.

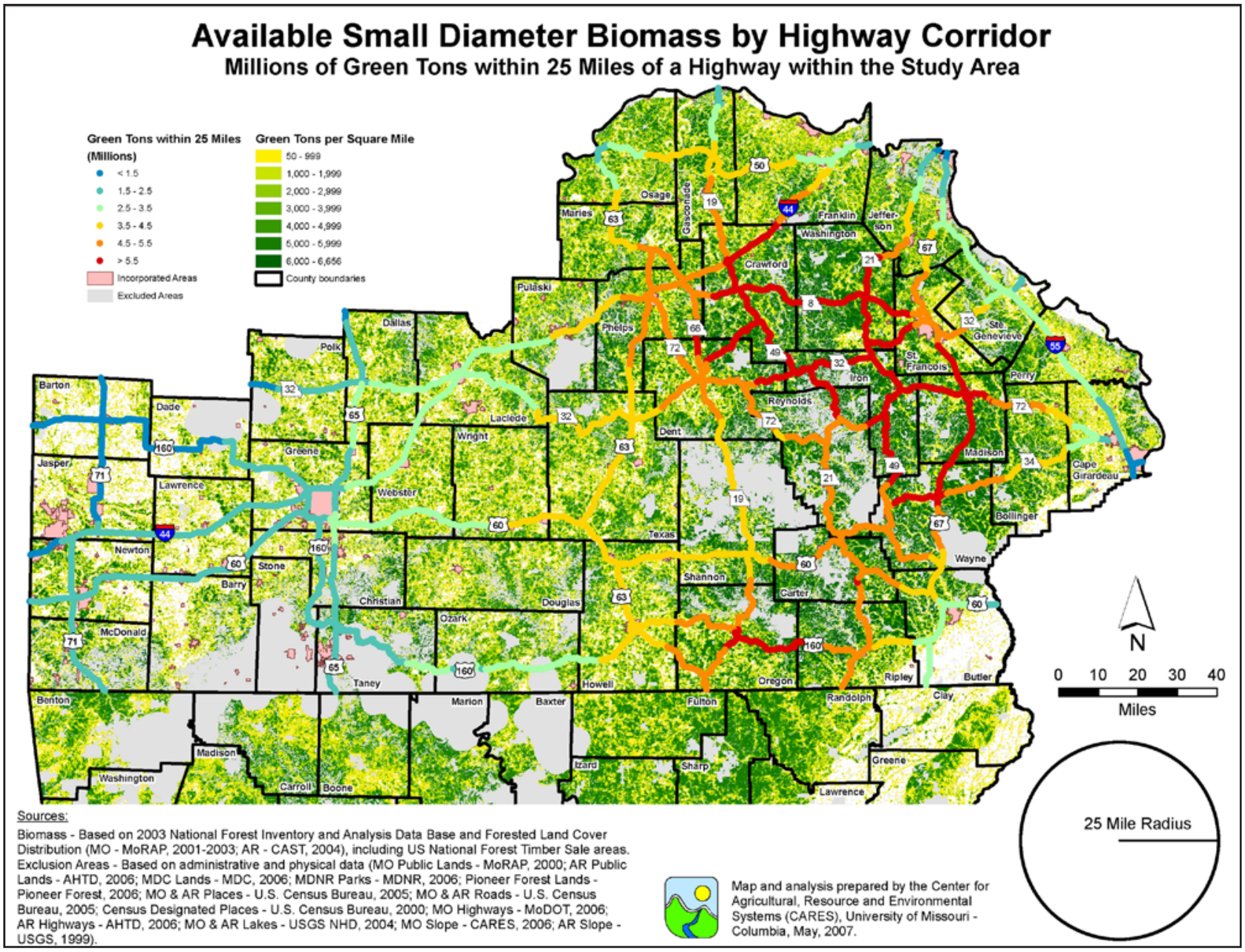

Figure 1.—Spatial distribution of available all-live biomass (green tons) across southern Missouri and within a 25-mile radius of major highway corridors.

PRELIMINARY SUSTAINABILITY ANALYSIS

Table 2 shows the annual forest biomass (green tons) and energy (million BTUs) that would be available for a wood-to-energy facility in Fredericktown, MO, as the radius of the source area expands in 5-mile increments. Available forest biomass was calculated by dividing the forested acres within the source area by 20 (for a 20-year thinning cycle), multiplying by either 0.05 or 0.30 (for the level of landowner participation), and then multiplying by our "typical" biomass yield of 9.5 green tons per acre. To determine the available energy in BTUs we multiplied the green tons per year by 2,000 green lbs per ton and then multiplied that product by 4,300 BTUs per green ton (based upon 50 percent moisture content).

Electrical Energy

Our proposed 25 MW-power plant would require 187,878 green tons annually from slightly less than 20,000 acres. Applying straight arithmetic to a 20-year re-entry interval implies that only one-twentieth of the forested acres for a specified source area radius would be available in a given year. That assumption coupled with a landowner participation level of only 5 percent and 9.5 green tons from forest thinning operations, reveals that even a 50-mile radius would be able to supply only 25 percent of the 187,878 green tons needed.

Table 2.—Annual forest biomass (green tons) and energy (million BTUs) that would be available for a wood-to-energy facility in Fredericktown, MO, as the source area expands based upon a 20-year thinning cycle and landowner participation levels of 5 and 30 percent

Source area radius (miles)	Total acres within source area	Forested acres within source area	Available biomass from forested acres (green tons)		Available energy from forested acres (million BTUs)	
			5% Landowner participation[1]	30% Landowner participation[2]	5% Landowner participation[3]	30% Landowner Participation[3]
5	42,164	23,180	551	3,303	4,735	8,407
10	158,121	97,018	2,304	13,825	19,816	118,896
15	367,632	225,338	5,352	32,111	46,025	276,152
20	649,358	387,393	9,201	55,204	79,125	474,750
25	1,016,054	599,098	14,229	85,371	122,366	734,195
30	1,455,881	805,410	19,128	114,771	164,505	987,030
35	1,916,480	989,830	23,508	141,051	202,173	1,213,037
40	2,305,024	1,148,393	27,274	163,646	234,559	1,407,356
45	2,632,191	1,326,623	31,507	189,044	270,963	1,625,776
50	2,951,908	1,507,945	35,814	214,882	307,998	1,847,987

[1]Available biomass (green tons/yr) = (forested ac/20 yr)*(0.05)*(9.5 green tons/ac)
[2]Available biomass (green tons/yr) = (forested ac/20 yr)*(0.30)*(9.5 green tons/ac)
[3]Available energy (million BTUs/yr) = (green tons/yr)*(2,000 green lb/green ton)*(4,300 BTUs/green lb)

However, if the participation level increased to 30 percent, then all of the plant's energy need could be supplied within a 45-mile radius. The visual impact of these harvesting operations across the landscape would be minimal because only 20,000 acres out of the 1,326,623 forested acres would be thinned in a given year.

Thermal Energy

A thermal plant of similar design to the Northwest University facility would require 29,000 green tons of wood annually from 3,125 acres of forest. With only one out of 20 landowners participating, our proposed sustainable silvicultural prescription would dictate a source area radius of 40 to 45 miles. If the participation level could be increased to one out of 10 landowners, the source area radius would shrink to 15 miles.

While raw material costs can be greatly reduced, the capital cost of plant construction for a facility that produces only low-pressure steam would probably result in a very unfavorable return on the initial investment. The capital cost of building these bioenergy plants will make it critical that every available BTU be converted to its highest and best use first and then capture unused energy in the form of these lower-value energy products, such as low-pressure steam for thermal uses.

Liquid Bio-fuels

A bio-refinery consuming 200,000 green tons annually would require forest thinnings from 21,000 acres. As for the electrical power plant, this facility would have only a fraction (18 percent) of its raw material need met if only 5 percent of the landowners within 50 miles of the plant thinned their forests. However, if the participation level increased to 30 percent then all the plant's wood fiber need could be supplied within a 45-mile radius.

ADDITIONAL CONSIDERATIONS

We realize that one silvicultural prescription will not fit all forested sites in the Missouri Ozarks. Ongoing forest health issues, such as oak decline, and upcoming open woodland restoration efforts on the Mark Twain National Forest will dictate prescriptions more aggressive than simple forest thinning. As a result, more than the 9.5 green tons from our "typical" acre will be available, potentially allowing smaller source areas for a wood-to-energy facility.

The area required to sustain a bioenergy plant could also be reduced by taking into account fiber from mixed stands of oak and pine, or even pure stands of pine. These cover types were intentionally omitted from this analysis in an attempt to provide as uniform a feedstock as possible given (1) the mosaic of the state's forests and (2) the fact that boilers and the current technology of bio-refineries tend to like uniform raw material in order to maximize product yield and minimize maintenance and repair costs.

Any financial analysis for a bioenergy plant will have to consider the cost of harvesting and transporting the wood to the power/thermal plant or bio-refinery. This is where the real challenge lies. For forest thinning operations to be economical, the number of times the tree/log/residue is handled must be minimized. For the operation to be sustainable, there must be minimal damage to the trees left standing and other best management practices followed. In addition, increasing fuel costs will put pressure on the distance that chips or round wood can be economically delivered from the forest to the bioenergy plant. These added costs will either limit the size of wood-to-energy enterprises, encourage mobile bio-refineries, or result in more aggressive harvesting. The last outcome has the potential of raising heated debate similar to the chip mill controversy of the late 1990s; another option for removing low-grade material from Missouri's forests may be eliminated.

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