Supply of Woody Residuals in the Northwest Region of Arkansas (2017) for Energy Production

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Abstract

Northwest Arkansas was identified as a region of interest for the production of wood-fueled electrical power due to its pervasive timber industry and need for cost-effective forest management. It is believed that by utilizing wood residuals produced from sawmill operations, a stable source of revenue could be provided to local wood processing businesses while simultaneously providing clean energy to the region. In order to evaluate the amount of available material available for energy production, all known mills were surveyed within the 16-county study region for their annual production of sawdust, slabs, and other residual products. Data on production of residuals were developed into supply curves and equations. Supply was found to be inelastic for both hardwood and softwood mill residuals in the region. Given that residual production is a secondary effect of timber processing, supply inelasticity is expected. Increasing the quantity of mill residuals in the region will likely be accompanied by greater-than-proportional price increases. We determined that 96,744 tons of ovendried material would be available annually for purchases at a delivered price of $38 per ton. With this quantity, the region could be expected to support a small combined heat and power energy facility with output between 5 and 10 MW.

Wood-fueled electric power is regarded by many as a renewable, near–carbon-neutral source of energy. To date, however, the industry has remained largely underdeveloped within the United States due to technological limitations associated with the production of high-yield energy products, environmental sustainability, and the competitive price of fossil fuels (Shivan and Mehmood 2010). The proliferation of wood-fueled electrical power will depend on increasing demand and prices for energy and increasing production of solid wood products, resulting in a greater supply of mill residuals. Regions within the United States where such a proliferation may be reasonably expected are likely those with rich timberland resources and well-developed forest products industries. For this reason, Arkansas has been identified as a prime candidate for expanded wood energy development.

Northwest Arkansas has a strong relationship with its forest industries in large part due to a significant woodland presence. Forestry directly contributes 1.2 percent of the regional value added, which, notably, is twice the national average (IMPLAN 2015). Within the past three decades, however, unstable market conditions and mounting environmental pressures have somewhat suppressed forest cutting and management activities, leading to declines in both stand quality and market development (US Forest Service n.d.). It is possible that the steady increase in demand for wood products, accompanied by the expansion of wood-fueled electrical power production, would stabilize the wood industry of northwest Arkansas and increase revenues to mills in the region.

Local demand for timber within the northwest sector of Arkansas is in large part supplied by numerous small-scale hardwood sawing mills with annual processing capacities typically below 24,000 tons. Mills of such sizes often specialize in the creation of cut lumber, railroad ties, or secondary products, such as pallets and flooring (Arkansas Forestry Commission 2017). The ability of these mills to sell or repurpose the waste materials associated with wood processing depends largely on factors such as location, local demand, and on-site equipment. Furthermore, the stability of small hardwood mills in the region is not always guaranteed. Although the United States has historically represented the single largest consumer of raw timber

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Forest Prod. J. 69(3):195–204.
doi:10.13073/FPJ-D-18-00048

products in the world, with housing development and paper production generating the chief demand, the use of wood products has for the past several years experienced sweeping declines (Prestemon et al. 2015). Changes in market conditions resulting from the 2008 recession and dramatic declines in home building disproportionately affected regions reliant on timber economies, including northwest Arkansas. Small sawmills, such as those typically found in northwest Arkansas, are particularly susceptible to market downturns.

Despite this, one particular area of the wood products market is tentatively lucrative for further development in the region. Woody biomass remains a core component of renewable power generation and could, in areas such as northwest Arkansas, be further explored. On a broader scale, the US South has especially benefited from global demand for wood-fueled electrical power, producing 63 percent of North America's exported wood pellet volume (Miner et al. 2014).

Certain studies have emphasized environmental benefits deriving from wood pellet use through the substitution of greenhouse gas-emitting fossil fuels (Miner et al. 2014). This production in pellets is supplied almost entirely from early thinning operations of plantation pine that are surplus to the needs of declining paper industry. It is, however, necessary to acknowledge trade-offs associated with certain other forms of woody biomass crops, namely, switchgrass and sorghum. Landscape-level impacts have garnered considerable concern given that energy crop cultivation requires the greatest amount of dedicated land per unit of energy produced as compared to all other fuel sources (McDonald et al. 2009). Should the demand for wood pellets and other forms of wood-fueled electrical power grow exceptionally, it is possible that short-rotation woody biomass crops may become favored over forest systems for biomass development. Should this occur, ecosystem benefits associated with forest cover, such as clean water, biodiversity, and wildlife habitat, could be drastically reduced in the face of land conversion (Costanza et al. 2017).

Within the context of this study, however, many of the aforementioned drawbacks associated with wood-fueled electrical power are far less likely to be incurred due to the nature of the feedstock being targeted for consumption. Woody residuals associated with sawmilling operations are produced as a by-product and in many circumstances may be regarded as a low-value waste material. By consuming these materials for energy production in lieu of dedicated energy crops, the need to convert land toward crop production is avoided, thus allowing for more sustainable land management practices to continue.

Woody mill residuals could provide an ideal alternative for electrical energy production as long as raw materials, production costs, and delivery costs are competitive with electricity generated from fossil fuels. Industrial natural gas prices in Arkansas for 2017 averaged $6.67 per thousand cubic feet, well above the national average of $4.10 per thousand cubic feet (US Energy Information Administration [EIA] 2018a). At the same time, according to the USDA Fuel Value Calculator, the values of green wood for electrical generation in Arkansas and the whole United States are $470 per ton and $289 per ton, respectively. Based on higher fossil fuel energy costs and the resulting higher green wood energy value, Arkansas would seem to be well positioned to explore wood-fueled electrical generation.

In response to these trends, it has been suggested that wood residuals, such as sawdust, bark, and slabs, could serve as an affordable fuel stock. As it stands, these products often lack a dependable market to accommodate their use and disposal, thus burdening mill owners who must contend with accumulating piles of unused materials on their properties. At times, it may even become necessary to pay to have residuals removed. Such a scenario threatens to negatively impact communities with strong ties to local timber industries.

A resurgence in demand for woody mill residuals would likely improve economic outlooks. The establishment of a moderately sized pellet-burning plant or boiler-driven combined heat and power facility may be justified if the supply of wood residuals is sufficient and acquisition prices fall within reasonable limits. Achieving this, however, will also depend on a regional ability to cut and process timber consistently. Should a new residual market emerge in the region, local mill operations may witness greater profit margins and an improved long-term outlook.

Prior research has determined that within much of the southern United States, mill residuals already have become an established component of bioenergy production, industrial fuel, and fiber product production (Joshi et al. 2014, Pokharel et al. 2019). However, given the typical small scale of sawmilling operations within the target region, an assumption was made at the outset of this study that producers of woody residuals would have limited means to efficiently and profitably dispose of waste materials due to limited market opportunities and a lack of on-site wood fuel facilities. It was anticipated that some mills may be able to sell some limited quantity as a charcoal base or animal bedding, but a new source of demand would net an overall positive effect for the region. The actual volume of residuals available at a reasonable price will likely serve as a substantial factor for determining the feasibility of any local energy facility and at what scale it would operate. The objective of our study was to determine the quantity and selling prices for woody biomass residuals in northwest Arkansas and establish a quantitative relationship between price and quantity: a supply curve.

Methods

The underlying methodology of this research is in large part similar to that of a 1992 study examining the residual production of primary forest product mills across the entire state of Arkansas (Greene et al. 1992). Although the number of wood processing facilities in Arkansas declined from 438 in 1992 to 206 in 2017, most of those changes have occurred in the southern region of the state, where paper mills and sawmill capacity consolidation occurred through investment and capacity increases in large southern pine lumber production. The wood processing industry in northwest Arkansas has remained largely unchanged in the past 30 years and is still dominated by much smaller hardwood mills processing railroad ties, cants, and lumber. There are few outlets for mill residues in the region due to the fact that paper mills capable of using hardwood residuals are located in the southern portion of the state and the one paper mill located just outside the study region uses recycled cartons and virgin softwood fiber. The types of residuals stated by Greene et al. (1992), largely green chips, slabs, shavings, chunk wood, and barky material, are still produced today. These residuals have limited market options in the region, represented largely by charcoal manufacturing, which uses barky wood slabs. However, where that study drew on a representative sample of mills for their collected data, it was our intention to capture the total population of operational primary and secondary mills to as near a degree as possible.

In order to ascertain the current state of northwest Arkansas' forest products market, it was necessary to identify all operational wood processing facilities within a preselected 16-county region. The counties sampled include Benton, Boone, Carroll, Crawford, Franklin, Johnson, Logan, Madison, Marion, Newton, Pope, Scott, Searcy, Sebastian, Washington, and Yell (Fig. 1). A list of all wood processing facilities for the region was obtained (Arkansas Forestry Commission 2017) and used as our initial contact list. Additional mills discovered through travel and correspondence were added to the list during the data collection period.

A questionnaire (Fig. 2) was developed with the intent to collect volume and price of woody residuals in three categories: clean sawdust, barky residuals, and chunk wood residuals. These categories were then further separated by hardwood and softwood classes. Through the questionnaire, we expected to determine whether these materials were being sold, used on-site, or disposed of by the mills. Prices and costs associated with the sale and disposal of residuals were collected as well. Although the form as administered was blank, the entries in Figure 2 display the summary results of the survey and are discussed below.

For each cell of Figure 2, N represents the number of mills reporting volume and pricing values for each residual type and usage. We indicate mean and standard deviation as $\bar{x}$ and s, respectively. Most mills supplied data for fewer than 10 cells due to factors such as processing capacity, wood selection, and sawing equipment.

Each of the mills was contacted via telephone to arrange a meeting between the owners of the facilities and the researchers. The data collection process itself took place between May and August 2017. Initially, after the research team visited the mill and spoke with the owner or mill manager, the questionnaire was left with the mill representative to fill out and return to the research team with a stamped, addressed envelope. The research team found that mill owners tended to be slow to reply or often provided incomplete data on the forms, thus requiring follow-up calls and visits. In response, a new approach was implemented in the form of a lengthier and more detailed interview during each mill visit. The researchers would request a brief tour of the facilities and note information pertaining to wood processing and residual production.

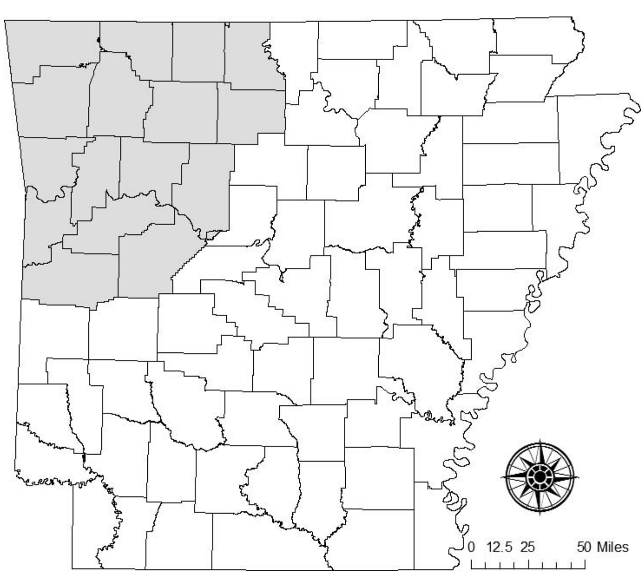

Figure 1.—Map of the 16-county study area within northwest Arkansas where the study of mill residual production was conducted.

Following the tour, one researcher engaged the mill representative with questions related to residual production and prices, while a second researcher took notes of all commentary. The interviews typically lasted between 30 and 90 minutes and resulted in more complete and comprehensive data from the mills. This data were used to generate a series of aggregate supply curves relating the quantity of wood residuals to the willingness to sell prices expressed by the mill owners. By associating the optimal outputs of a product to different potential prices, it was possible to generate a reasonable estimate of available supply for any price a buyer is willing to offer (Klemperer 1996).

Volumes were sorted by price, and cumulative volumes were tabulated. It was assumed that volumes associated with a lower willingness-to-sell price would also be available at a higher price. This information was then compiled into cumulative volumes by price. A small number of mills paid to remove or dispose of woody residuals. In this case, a price of $0 was assigned to those volumes, as it was anticipated that that mill owners would not be willing to pay to supply residuals for a new wood-using facility. Eight supply curves were developed for the following woody residual classes: hardwood clean sawdust, hardwood barky residuals, hardwood woody residuals, total hardwood residuals, softwood clean sawdust, softwood barky residuals, softwood woody residuals, and total softwood residuals.

Linear regression analysis was performed with SYSTAT 13 software in order to generate equations that could be used to determine the elasticity of supply for the total softwood and total hardwood curves. Given the expected shape of supply curves, a regression equation with one or more polynomial transformations of the independent variable of price is an appropriate technique for modeling the dependent variable of quantity (Weisberg 1985). Due to the limited number of data and price levels for individual residual classes, data for all softwood and all hardwood residual classes were pooled for regression analysis.

We next sought to establish capacity estimates for the surveyed mills. For this portion of data analysis, we referred to the Arkansas Forestry Commission's (2017) sawmill size class ranges for annual processing capacities. For most classes, we simply took the midpoint of the ranges. G-class mills, the largest class, were handled differently, given that their range extends from 200,000 tons to infinity. Instead of a midpoint, we took the minimum value of 200,000 tons to serve as our representative value (Table 1). These capacities estimates were then assigned to each identified mill. This allowed us to estimate sample size based not only on the number of mills surveyed but also, more appropriately, on mill capacity.

Most surveyed mills handled either hardwood or softwood material exclusively, and thus the previously

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Questions? See instructions on back of this form.

Mill Residual Data Form		Hardwood (Tons/year)	Softwood/Pine (Tons/year) (note if cedar)
Residuals produced and used on site	Clean sawdust	1 N = 4, $\bar{x}$ = 3882, s = 4291	2 N = 0, $\bar{x}$ = 0, s = 0
	Bark, barky sawdust, or other residuals that are primarily bark	3 N = 1, $\bar{x}$ = 2500, s = 0	4 N = 1, $\bar{x}$ = 750, s = 0
	Woody residuals Clean chips, slabs, shavings, chunk wood	5 N = 7, $\bar{x}$ = 4826, s = 11114	6 N = 0, $\bar{x}$ = 0, s = 0
	At what price ($/ton) would you sell above material to outside buyer? If price is different by residue class, please note.	7 a. N = 2, $\bar{x}$ = $50, s = 0; b. N = 1, $\bar{x}$ = $5, s = 0; c. N = 6, $\bar{x}$ = $34, s = 24	8 a. N = 0, $\bar{x}$ = $0, s = 0; b. N = 1, $\bar{x}$ = $70, s = 0; c. N = 0, $\bar{x}$ = $0, s = 0
Residuals produced on site but not used or sold	Clean sawdust	9 N = 22, $\bar{x}$ = 2001, s = 4736	10 N = 2, $\bar{x}$ = 238, s = 159
	Bark, barky sawdust, or other residuals that are primarily bark	11 N = 9, $\bar{x}$ = 1457, s = 290	12 N = 5, $\bar{x}$ = 718, s = 1021
	Woody residuals Clean chips, slabs, shavings, chunk wood	13 N = 9, $\bar{x}$ = 1457, s = 2045	14 N = 6, $\bar{x}$ = 1640, s = 1870
	If material above is being landfilled, what is your cost per ton of disposal? If cost is different by residue class, please note.	15 a. N = 1, $\bar{x}$ = $40, s = 0; b. N = 0, $\bar{x}$ = $0, s = 0; c. N = 1, $\bar{x}$ = $4, s = 0	16 a. N = 1, $\bar{x}$ = $6, s = 0; b. N = 0, $\bar{x}$ = $0, s = 0; c. N = 1, $\bar{x}$ = $21, s = 0

RESIDUES THAT ARE PRODUCED ON SITE AND SOLD

		Hardwoods		Softwood/Pine	
		Tons/year	$/ton*	Tons/year	$/ton*
Residuals produced on site and sold	Clean sawdust	17 N = 16, $\bar{x}$ =5405, s = 5831	18 N = 16, $\bar{x}$ = $6, s = 10	19 N = 6, $\bar{x}$ = 2297, s = 2619	20 N = 6, $\bar{x}$= $10, s = 9
	Bark, barky sawdust, or other residuals that are primarily bark	21 N = 6, $\bar{x}$ = 11113, s = 9765	22 N = 6, $\bar{x}$ = $10, s = 9	23 N = 4, $\bar{x}$ = 4113, s = 3412	24 N = 4, $\bar{x}$ = $19, s = 12
	Woody residuals Clean chips, slabs, shavings, chunk wood	25 N = 24, $\bar{x}$ = 4866, s = 5204	26 N = 24, $\bar{x}$ = $13, s = 4	27 N = 7, $\bar{x}$ = 1218, s = 1840	28 N = 7, $\bar{x}$ = $30, s = 33

*If more than one price and tonnage combination exists in a category, write both on the survey form.

Figure 2.—Questionnaire requesting annual volume and price information for various wood residuals produced by sawmills within the 16-county study region. For each question, the sample size (N), mean ($\bar{x}$), and standard deviation (s) have been provided. For questions 7, 8, 15, and 16, the responses are separated by (a) clean sawdust; (b) bark, barky sawdust, or other residuals that are primarily bark; and (c) woody residuals, clean chips, slabs, shavings, and chunk wood.

INSTRUCTIONS FOR FILLING OUT MILL SURVEY FORM

If you have any questions about filling out this form, please call Matthew Pelkki at (870) 460-1949.

Box Number(s)	Data desired
1, 2	Tons of clean sawdust produced annually and used for on site for energy, heat, or some other purpose but not sold. Box 1 is hardwoods, box 2 is softwoods/pine.
3, 4	Tons of barky residuals or sawdust mixed with bark that are produced annually and used on site for energy, heat, or some other purpose but not sold. Box 3 is hardwoods, box 2 is softwoods/pine.
5, 6	Tons of woody residuals (chips, slabs, or chunk wood) produced annually and used for energy, heat, or some other use but not sold. Box 5 is hardwoods, box 8 is softwoods/pine.
7, 8	Price, in $/ton, at which residuals listed in boxes 1-6 may be purchased. Box 7 is hardwoods, box 8 is softwoods/pine. If prices vary by product, please list each separately and indicate product and price combinations. These prices for these products can also be written next to the tons in boxes 1-6 as appropriate.
9, 10	Tons of clean sawdust produced annually and not used on site or sold. Box 9 is hardwoods, box 10 is softwoods/pine.
11, 12	Tons of barky residuals or sawdust mixed with bark that are produced annually and not used on site or sold. Box 11 is hardwoods, box 12 is softwoods/pine.
13, 14	Tons of woody residuals produced annually and not used on site or sold. Box 15 is hardwoods, box 14 is softwoods/pine.
15, 16	If materials not sold or used on site (boxes 9-14) are sent to a landfill or otherwise disposed of on site (burned, pushed offsite to rot/decay), what is the cost of disposal per ton? Box 15 is hardwoods, box 16 is softwoods/pine. If costs vary by residual material, please list each separately and indicate material and cost combinations. The costs for disposal can also be written next to the tons in boxes 9-14 as appropriate.
17, 19	Production of clean sawdust (hardwoods – box 17, softwoods – box 19) produced per year and sold. Please indicate in tons. The prices for the sold sawdust is entered in box 20 for hardwoods, box 20 for softwoods/pine.
18, 20	Price per ton of clean sawdust sold (hardwoods – box 18, softwoods – box 20). If tiered prices, list separate tonnage in each box and then prices in box 18 if hardwoods or box 20 if softwoods. By tiered prices, if you sell some sawdust for $X per ton and some for $Y per ton, please list each tonnage and price combination in boxes 17 and 18 for hardwoods and boxes 19 and 20 for softwoods/pine.
21, 23	Production of bark-based residuals (hardwoods – box 21, softwoods – box 23) produced per year and sold. Please indicate in tons. Prices for these materials are to be listed in boxes 22 and 24.
22, 24	Price per ton of bark-based residuals sold (hardwoods – box 22, softwoods – box 24). If tiered prices, list separate tonnage in each box and then prices in box 22 if hardwoods or box 26 if softwoods. For a description of how to list tiered prices, see the description for boxes 18, 20 (above).
25, 27	Production of woody residuals (hardwoods – box 25, softwoods – box 27) produced per year and sold. Please indicate in tons. Prices for these materials are to be listed in boxes 26 and 28.
26, 28	Price per ton of woody residuals sold (hardwoods – box 26, softwoods – box 28). If tiered prices, list separate tonnage in each box and then prices in box 26 if hardwoods or box 28 if softwoods. For a description of how to list tiered prices, see the description for boxes 18, 20 (above).

When completed, please return in addressed and stamped envelope to:

Matthew Pelkki
University of Arkansas at Monticello
School of Forest Resources
Monticello, AR 71656-3468

Figure 2.—Continued.

assigned capacity estimate was used to represent annual hardwood or softwood processing. For instances in which a mill processed both wood types, we inquired as to the percent use of hardwood and softwood and then applied these ratios to the original capacity estimate. Once the individual hardwood and softwood capacities were determined, these values were summed to find the regional capacity of sawmills within the 16-county study area.

Results

We identified a total population of 56 mills in the region and sampled 51 for a response rate of 91 percent. The annual timber processing capacity of our 16-county region is 1,404,000 green tons for hardwood and 528,000 green tons for softwood. The sampled mills accounted for 1,345,280 tons of hardwood production and 262,400 tons of softwood production (Table 2). This represents 96 percent of the hardwood capacity and 50 percent of the softwood capacity in northwest Arkansas. We determined that 377,125 tons of hardwood residuals and 53,410 tons of softwood residual were produced within the region in 2017 (Table 3).

Figures 3 and 4 provide the supply curve information derived from the data by product type and totals, respectively. The supply curve models regional quantities of woody mill residues as a function of the price a buyer might be willing to pay. Equations 1 and 2, featured below, are the regression equations fit to the total residuals for hardwoods and softwoods, respectively. Figures 5 and 6 provide the predicted quantities of hardwood and softwood residuals, respectively. Fit statistics for each equation are shown in Tables 4 and 5.

$$Q_{\text{hardwoods}} = 53,430.989 + 16,289.216P - 287.578P^2 + 1.719P^3 \tag{1}$$

$$Q_{\text{softwoods}} = 14,745.080 + 2553.379P - 54.584P^2 + 0.371P^3 \tag{2}$$

where

Q = quantity per short ton, and

P = price per short ton.

The price range found for materials in the region ranged from \$0 to \$70 for hardwood materials and \$0 to \$100 for softwood. A small percentage of residuals are available only at prohibitively high prices due to internal use by one mill that uses its own residuals to generate heat for kiln operations (200 tons of softwood woody biomass at \$100 per ton). This price reflects the replacement costs that would be required by that mill to convert to another source of energy. In fitting the regression equation, this price and quantity was found to be an outlier and was removed from the data set when fitting Equation 2, above.

The supply elasticity for hardwood residuals ranged from 0.058 to 0.583 with an average of 0.45, while softwood residual elasticity ranged from 0.023 to 0.497 with an average of 0.31. All values indicate an inelastic relationship.

Discussion

A substantial portion of residual producers within the study region have found applications for their waste materials, thus dispelling any notion that these products currently represent a total revenue sink. Common applications were found to include animal bedding, mulch production, and, most substantially, charcoal manufacturing. In fact, our results have indicated that a relatively low volume of materials are available at no cost, indicating that mill owners within the region are, for the most part, finding uses on-site for their residuals or have found outside buyers to remove these products. However, selling prices are often so low as to only cover loading costs and thus do not represent an actual source of profit for many mills. Sales of woody residuals in the region are a miscellany of buyers, quantities, prices, and timing of sales, which makes marketing complex for the small mills. The introduction of additional demand for woody mill residuals in the region could result in an increase in the revenue received by mills for their residuals and provide simplicity and stability in the marketing and sales of woody residuals.

The supply of these residuals is inelastic, meaning that prices rise proportionately faster than quantities in the supply relationship. Based on the elasticities found, a 10 percent increase in the price offered for mill residuals would result in only a 4.5 percent increase in hardwood residuals offered for sale. For softwood residuals, the 10 percent increase in price would increase quantity by only 3.1 percent. This is intuitively sound given that residuals are a by-product of wood processing. To produce more residuals, it is necessary for the mills to increase production of their primary products, as diverting to produce a lower-valued product would be irrational.

One major limitation of our study, however, was our inability to sample a substantial portion of the softwood residual supply. We estimate that approximately half of the region's supply of softwood residues is produced by two high-capacity facilities. Due to concerns regarding the practical anonymity of reported data, these mills opted not to relinquish their production quantities or prices. That said, residuals at these two facilities are utilized internally, and excess materials are marketed thoroughly; thus, it is unlikely that any residuals from these facilities could be cost-effectively included to supply a new wood energy facility in the region.

Regardless, it is still possible to speculate as to the feasibility of a wood-fueled combined heat and power energy plant. First, however, it is necessary to understand the costs associated with the acquisition of materials, as

Table 1.—Sawmill capacity estimates by class. Estimates are based on annual processing capacity estimates as defined by the Arkansas Forestry Commission. A midpoint of size ranges was selected as a representative estimate for all size classes except G. The G class encompasses all mills with an annual processing capacity of 200,000 tons and above; thus, 200,000 was selected as the representative point.

Mill class	Annual estimated capacity (tons/yr)
A	4,000
B	16,000
C	32,000
D	60,000
E	100,000
F	140,000
G	200,000

Table 2.—Estimated northwest Arkansas regional timber processing capacity.

	Softwood (tons/yr)	Hardwood (tons/yr)	Total (tons/yr)
Sampled	262,400	1,345,280	1,607,680
Unsampled	265,600	58,720	324,320
Total capacity	528,000	1,404,000	1,932,000

Table 3.—Residuals available for purchase within northwest Arkansas.

Hardwood	Tons/yr	Softwood	Tons/yr
Clean sawdust	143,623	Clean sawdust	14,259
Barky residuals	70,130	Barky residuals	20,789
Woody residuals	163,372	Woody residuals	18,362
Regional total	377,125	Regional total	53,410

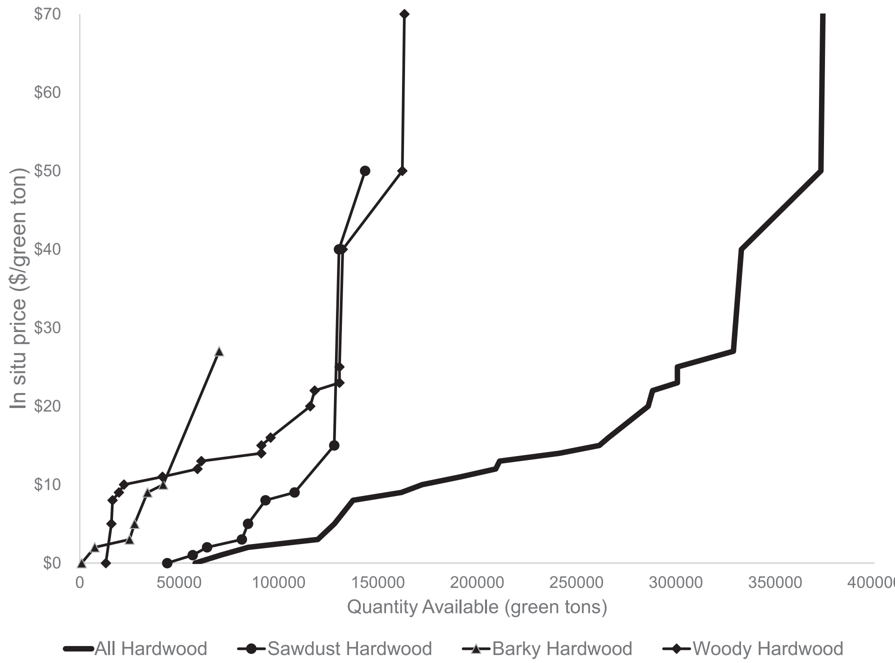

Figure 3.—Aggregate supply curve of all hardwood residuals produced within northwest Arkansas.

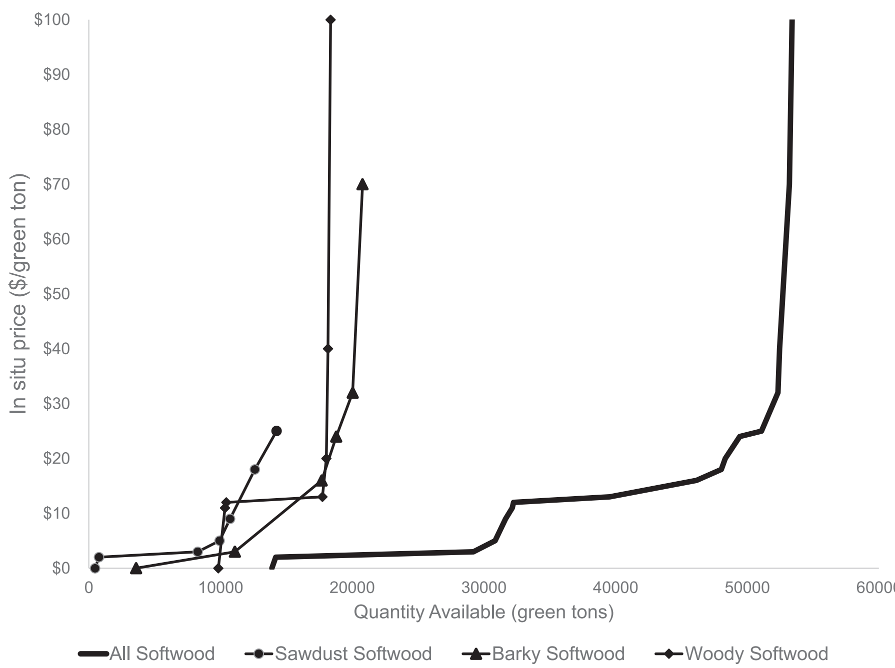

Figure 4.—Aggregate supply curve of all softwood residuals produced within northwest Arkansas.

these will ultimately be a limiting factor on the productivity of an energy facility.

Based on personal communications with a preestablished 27-MW biomass power plant, we can infer that a reasonable estimate of the value of residual materials is roughly $38 per ovendried ton—this is the amount a wood-fired electric power plant can afford to pay for woody biomass. Operating under the assumption that an average moisture content (wet basis) for available materials will be 50 percent, a price of $19 per green ton for delivered woody biomass is a reasonable estimate of the value of green woody biomass delivered to an energy facility. The estimated average haul distance for materials in the US South is 76 miles at a rate of 12.5 cents per mile (Harris 2017), or an average haul cost of $9.50 for every green ton of residual product delivered.

Assuming that the delivered biomass is worth $19 per green ton and that the mill must pay $9.50 for hauling costs, we are left with the remaining $9.50 to pay for the biomass in situ at the mill where it is produced. Using the supply data developed for northwest Arkansas, approximately 193,488 tons of green residual material are available at this price per

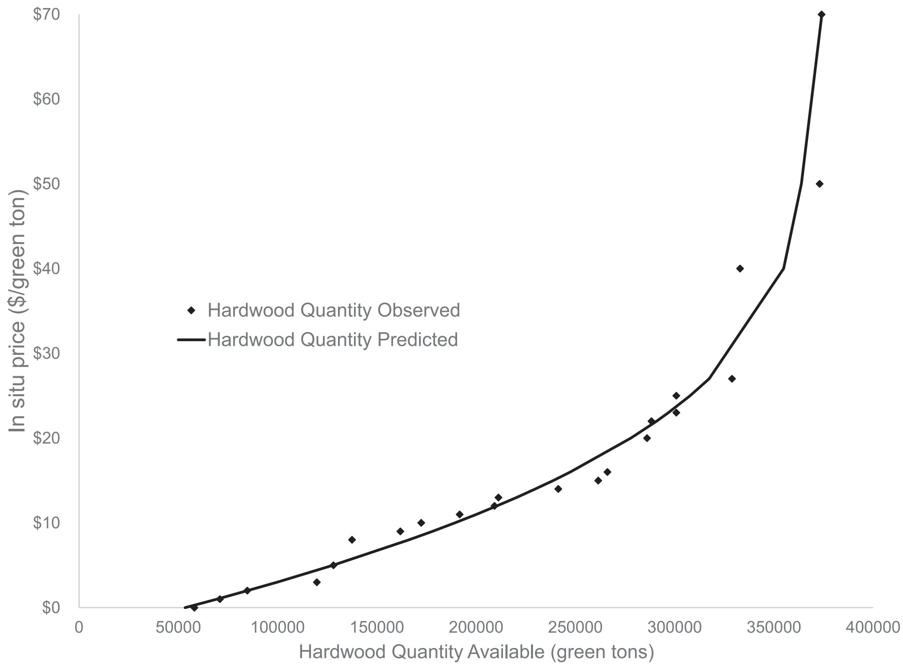

Figure 5.—Predicted quantity of hardwood residuals produced annually within the study region versus observed quantities sampled during the data collection period.

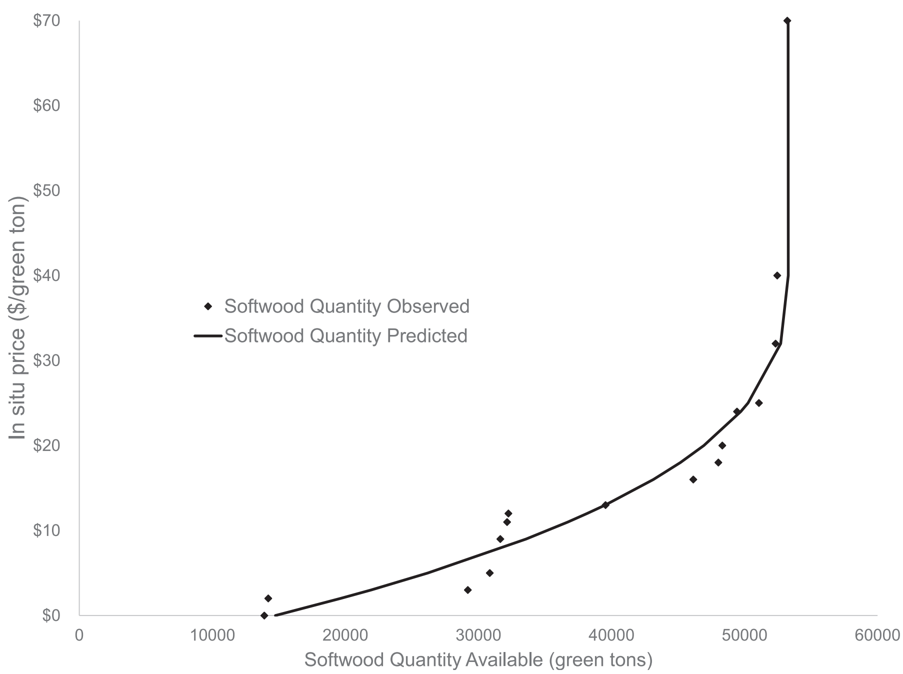

Figure 6.—Predicted quantity of softwood residuals produced annually within the study region versus observed quantities sampled during the data collection period.

year, which would translate into 96,744 ovendried tons. Wood-fueled electrical energy is typically produced at a rate of 1 MWh for every ton of ovendried material, meaning 8,760 tons of material would be required annually for each megawatt-hour produced. For reference, a typical 20-MW energy facility is reported to use between 160,000 and 200,000 tons of ovendried material per year (Mayhead and Shelly 2011).

In consideration of the quantity available, a 5- to 10-MW facility would be feasible for the region based on mill residuals alone. Supply is likely to fluctuate with market and environmental conditions; thus, a smaller-scale facility is a safer, maintainable option. One possible method to provide a more stable supply of materials would be to open residual purchases to mills located outside of Arkansas provided they are located a reasonable distance away. Alternatively,

Table 4.—*Fit statistics for hardwood regression curve.* N *represents the number of price tiers.*

Hardwood regression equation statistics					
N	22				
R^2	0.990				
Adjusted R^2	0.978				
Standard error of estimate	14,486.649				
Coefficient		Standard error	t value	P value	
Regression coefficients					
Intercept (β_0)	53,430.989	7,759.294	6.886	0.000	
P	16,289.216	1,163.666	13.998	0.000	
P^2	−287.578	45.736	−6.288	0.000	
P^3	1.719	0.462	3.721	0.002	
Source	Sum of squares	Degrees of freedom	Mean square error	F	P value
Analysis of variance					
Regression	1.929E + 011	3	6.430E + 010	306.374	0.000
Residual	3.778E + 009	18	2.099E + 008		

Table 5.—*Fit statistics for softwood regression curve.* N *represents the number of price tiers.*

Softwood regression equation statistics					
N	16				
R^2	0.964				
Adjusted R^2	0.911				
Standard error of estimate	3,927.917				
Coefficient		Standard error	t value	P value	
Regression coefficients					
Intercept (β_0)	14,745.080	2,526.123	5.837	0.000	
P	2,553.379	408.593	6.249	0.000	
P^2	−54.584	16.788	−3.251	0.007	
P^3	0.371	0.168	2.207	0.048	
Source	Sum of squares	Degrees of freedom	Mean square error	F	P value
Analysis of variance					
Regression	2.405E + 009	3	8.016E + 008	51.954	0.000
Residual	1.851E + 008	12	15,428,531.491		

residuals from forest logging operations could also be further explored as a potential raw material source.

Final factors to consider before attempting to introduce wood-fueled electrical power to the region are the costs of electrical generation and the impacts that any alternative energy facility may have on local residents. As one example, current estimates have placed the levelized cost of energy for a typical land-based wind farm somewhere between \$49 and \$52 per MWh (Stehly et al. 2016). In contrast, bioenergy may incur a levelized cost of energy of nearly \$100 per MWh (National Renewable Energy Laboratory 2018). The incorporation of wood-fueled electric power may incur a greater financial burden than its renewable competitors. Meanwhile, at 10 cents per kilowatt-hour, Arkansas currently hosts some of the lowest residential electricity prices in the nation (EIA 2018b). It is not unreasonable to assume that the populace would respond negatively to higher energy costs should they become too conspicuous. Northwest Arkansas is experiencing some of the fastest population growth in the region. The city of Fayetteville has a goal of 100 percent clean energy by 2030. Wood energy-derived electricity can be part of that solution. While electricity generated from wind farms in Oklahoma would likely hold a cost advantage, the local jobs and resiliency of energy diversity could counter the cost advantage in northwest Arkansas.

Conclusion

Based on the current production and prices for woody biomass in northwest Arkansas, we have determined that a 5- to 10-MW electrical generation facility could be supported solely by existing mill residuals. The supply curve was found to be inelastic. This means that changes in quantity will require two to three times a proportional change in prices for woody mill residuals. The benefit of a new residual market to sawmills in the region would be a stable, single demand source and higher revenues for mill residuals. The disadvantage is that increasing the size of a wood-fueled electrical power facility beyond 5 to 10 MW while maintaining a feasible price of delivered biomass will require additional woody biomass from a larger geographic region or from additional sources in northwest Arkansas, such as logging residues or dedicated woody energy crops. Future research expanding the geographic scope to southwest Missouri and northeast Oklahoma would determine if additional woody mill residuals were available at a suitable price.

Acknowledgments

This research was funded by the USDA National Institute of Food and Agriculture Project AR02624 and by the USDA Forest Service Southern Region Wood Innovations Program.

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