Assessment of Woody Biomass Availability from Surface Mining Operations in West Virginia

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Abstract

Gross biomass stocks were estimated during 2010 and 2011 on three areas to be surface mined in central West Virginia. Approximately 835 acres of forest lands had been harvested for merchantable timber on the study sites during 2009 and 2010, leaving wood fiber that was to be disposed of before mining. A total of 133 one-fifth-acre forest inventory plots were established to develop standing resource and logging residue estimates. The sampled plots were dominated by cucumber tree (*Magnolia acuminatae*), followed by red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), and yellow-poplar (*Liriodendron tulipifera*). The average diameter of all standing trees was 7.9 inches, and the average merchantable height of all trees was 32.5 feet. Biomass availability per acre before grubbing operations was estimated to be 31.3 green tons/acre, including 17.0 green tons/acre standing trees and 14.4 green tons/acre logging residues. When the estimated availability of 31.4 green tons/acre is extrapolated to the entire surface mine permit area, the total amount of gross biomass resources available is 26,160.6 tons and, when expanded statewide, represents 352,619 tons. The results indicate that a significant amount of woody biomass is available during surface mining operations in West Virginia.

West Virginia is a heavily forested state with a total of 4.7 million hectares (12 million acres) of forestland (Widmann et al. 2012). The state produces 2.4 million dry tons of wood residues per year, including 1.3 million dry tons of logging residue, 943,846 dry tons of mill residues, 118,839 dry tons of urban tree residue, and 12,742 dry tons of pallet residues (Wang et al. 2006). While the state provides ample supplies of natural biomass from wood wastes and woody materials, it is limited in terms of available acreage for the development of biomass cropping systems. Of the land remaining for feedstock production systems, those disturbed and reclaimed during mining operations may offer the best opportunity, because very little agricultural land is uncommitted.

The West Virginia coal mining industry is important to the economy and well-being of the state as well as the nation. West Virginia produces more coal than any other state except for Wyoming, and 43 of its 55 counties have reserves of minable coal. According to the US Department of Interior's Office of Surface Mining Reclamation and Enforcement (USDI OSM), a total of 1,802,316 hectares of land were under permit for surface coal mining and reclamation in the United States in 2008, of which 200,846 hectares were located in West Virginia (Kazar 2011). Surface mines in West Virginia account for nearly 60 million tons of production each year (West Virginia Office of Miners' Health, Safety, and Training 2011). Surface mining is a type of mining in which soil and rock overlying the mineral deposit are removed. Before mining operations, however, the land must be cleared of all vegetation, including trees and topsoil. As such, a significant amount of marketable timber and woody biomass is generated.

The West Virginia Office of Coalfield Community Development is currently pursuing development opportunities for the communities that are affected by surface mining. One new opportunity may be projects that generate energy from woody biomass that is produced during and after mining operations. Because feedstock availability is often a

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limiting factor for the development of new energy projects, a better understanding of woody biomass inventories on and adjacent to these project areas is critically needed. Currently, readily marketable roundwood is removed during the first phase of mine development. Following this harvest, contract crews clear the remaining woody vegetation during the ''grubbing'' phase. Fiber cleared during this stage is typically piled and burned to ready the site for mine development. Typically, operators pay upwards of $2,000/acre to clear these sites of the remaining wood fiber. While equipment used during these clearing operations is of much larger scale than that used during typical roundwood harvests in the region (e.g., Caterpillar D10/D11 dozers and 700 series off-highway trucks are common), the possibility exists to extract the remaining wood fiber using this clearing equipment. Before these operational systems can be investigated, however, the true extent of the remaining wood fiber needs to be assessed. Developing business opportunities around biomass feedstocks, especially those that can be integrated into coal systems, would also encourage the use of short-rotation woody crops and/or the reestablishment of forest cover on mined sites. Currently, the majority of mined sites in West Virginia are reclaimed to grassland habitats. The development of energy projects using biomass produced on these sites would increase the economic benefits to communities in these areas that typically are reliant on the coal mining industry and suffer when coal stocks are depleted. Likewise, technologies that make use of the wood fiber produced during mining operations would lessen the environmental impacts of the current system by reducing CO_2 emissions that are produced when the remaining wood fiber is burned during clearing operations.

The objective of this research was to estimate the amount of wood fiber that is available on surface mine sites during the secondary phase of fiber clearing in West Virginia. There has been increasing concern regarding the amount of wood fiber that is not being utilized and disposed of before coal extraction begins. Having a better understanding of gross biomass stocks as well as species compositions and piece size will help project developers understand the opportunity and help develop businesses that can process this fiber stream, which is costing coal operators a significant amount of money to remove from the sites. Likewise, assessing gross biomass stocks on these sites is the first step in determining an appropriate extraction system as well as technology for converting these stocks to energy products.

Methods

Surface mine operators in central West Virginia were contacted in 2009 and 2010 via phone and personal interviews to discuss the potential for conducting this project. Based on this initial screening process, three surface-mine development areas were visited during 2010 and 2011. These sites were chosen based on mine operator and landowner permissions. Approximately 835 acres had been harvested for merchantable timber on the three separate sites during 2009 and 2010. Harvesting had been completed on all sites, and the sites were being prepared for grubbing during the data collection period. Due to the ongoing mining operations on the three sites, a total of 586 acres were selected for this study: 481 acres on the first site, 35 acres on the second site, and 70 acres on the third site. The extent of the surface mine disturbance area was mapped, and a 100-m^2 grid square (10 by 10 m) was generated using a geographic information system for each site. A negative 50-m buffer was established to reduce edge effects during sampling. A total of 133 one-fifth-acre forest inventory plots were established at each of the grid intersections, including 84 plots on the first site, 14 plots on the second site, and 35 plots on the third site.

Both standing tree and logging residue data were collected on each site. For the purposes of analyses, all species were placed into five species groups (Table 1). Species and diameter at breast height (DBH) were recorded for each standing tree on all plots. To reflect size characteristics of local markets, top diameters to 4 inches were considered to be merchantable. This diameter cut-off corresponds with limits used by both engineered and pulp markets in the study area. The height to a 4-inch top (i.e., merchantable height [MHT]) was collected on every third plot. DBH was measured to the nearest 0.1 inch using standard diameter tape, and MHT was obtained to the nearest foot using a survey laser. The total green weight of a standing tree and the green weight to 4-inch merchantable top were determined using two nonlinear models, both developed by Wiant et al. (1977) from tree weights collected in West Virginia. The two models are expressed as

$$\mathrm{GW} = \beta_1 D^{\beta_2} \tag{1}$$

and

$$\mathrm{GW} = \beta_1 + \beta_2 D^2 + \beta_3 D \tag{2}$$

where GW is tree green weight (lb); β_1, β_2, and β_3 are species-specific parameter estimates given by Wiant et al. (1977); and D is DBH (in.). Equation 2 was used for estimating the green weight to the 4-inch merchantable top for those plots where MHT was known, and Equation 1 was used to develop biomass weight estimates for each tree sampled on all other plots. The use of two separate weight equations helped balance the time savings gained by not collecting height information with the extra accuracy gained when measuring MHT. The final unit of biomass weight was converted to tons per acre and averaged over all plots.

Line intersect sampling was used to estimate the quantity of logging residues on each plot. The details of the logged area analysis were described previously (Grushecky et al. 2006). Field technicians measured wood residue as they

Table 1.—Species represented in each of five species groups used in the summary of gross biomass stocks on surface mines in West Virginia.

Species groups	Represented species
Maple	Red maple (*Acer rubrum*) and sugar maple (*Acer saccharum*)
Oak	Chestnut oak (*Quercus prinus*), red oak (*Quercus rubra*), and white oak (*Quercus alba*)
Yellow-poplar	*Liriodendron tulipifera*
Cucumber tree	*Magnolia acuminatae*
Miscellaneous hardwoods	American beech (*Fagus grandifolia*), American elm (*Ulmus americana*), black birch (*Betula lenta*), black cherry (*Prunus serotina*), black gum (*Nyssa sylvatica*), hickory spp. (*Carya* spp.), sassafras (*Sassafras albidum*), sourwood (*Oxydendrum arboreum*), and white ash (*Fraxinus americana*)

walked along these transects, recording the diameter of each residue piece at the point where it intersected with the 100-ft nylon tape (diameter at intersection [DAI]). A residue piece was recorded if it was at least 4 inches in diameter at the small end and 4 feet in length. One of every four transects was sampled intensively to provide information related to residue characteristics. On intensive lines, measurements included the species, DAI, as well as the small-end diameter (to a minimum of 4 in.), large-end diameter, and piece length. The following equations developed by Van Wagner (1968) were used to calculate the volumes and weights of logging residues:

$$V = \frac{373.19\sum d^2}{L} \tag{3}$$

$$W = \frac{11.65S\sum d^2}{L} \tag{4}$$

where V is volume of logging residue (ft^3/acre), W is weight of logging residue (green tons/acre), S is the specific gravity of a particular species, d is the diameter of each piece at transect intersection (in.), and L is the transect length (ft).

Results

After the merchantable timber had been removed by logging contractors, the most commonly sampled species groups remaining included maple species (30.7%), followed by miscellaneous hardwoods (25.4%), cucumber tree (20.3%), yellow-poplar (12.1%), and oak species (11.6%). The number of trees per acre ranged from 0 to 255, with an average of 55. The average DBH and MHT was 7.9 inches and 32.5 feet, respectively. The oak species group had the largest average DBH and MHT among all standing trees (Table 2). The maple and miscellaneous species' groups had the greatest average whole tree and 4-inch merchantable top weight estimates (Table 3). Based on the average DBH of the sampled trees, the total standing tree green weight was estimated to be 17.0 tons/acre. The total green weight to 4-inch merchantable top, however, was only 6.6 tons/acre, less than half the total green weight of standing trees.

A total of 266 residue lines were sampled on the three investigated sites, representing 26,600 feet (~5.0 mi) of logging residue transects. Altogether, 788 pieces of logging residue were crossed by the sampling transects. The most frequently encountered species of logging residue was oak, representing 36.4 percent of the residue recorded along transects, followed by maple (24%), yellow-poplar (17%), and miscellaneous hardwoods (16.6%). Within the three sample sites, the average DAI with sampling transects for all residue was 6.2 inches. The yellow-poplar species group had the largest DAI (6.5 in.), followed by oak (6.5 in.), miscellaneous hardwoods (6.2 in.), maple (6.1 in.), and cucumber (5.9 in.).

Table 3.—Statistics of average green weight of standing trees (tons/acre) by species group on surface mine sites in West Virginia.

	Whole trees		4-in. dob trees[a]	
Species group	Mean	Max	Mean	Max
Maple	4.8	30.9	1.8	11.1
Oak	3.3	52.2	1.3	20.7
Yellow-poplar	2.2	43.8	0.8	17.8
Cucumber tree	2.3	29.6	0.9	11.0
Miscellaneous hardwoods	4.4	54.2	1.8	24.2

[a] dob = diameter outside bark.

The average weight and volume of logging residue left after harvest in the three sampled sites were 14.3 green tons/acre and 892.5 ft^3/acre, respectively. Oak was the most prevalent species group by weight or volume, averaging 5.4 green tons/acre (303.8 ft^3/acre) over the study sites, which account for approximately 38 and 34 percent of the total logging residue weight and volume composition, respectively, in this study (Table 4). Maple, miscellaneous hardwoods, yellow-poplar, and cucumber species followed the oak group, with 4.0, 2.4, 2.0, and 0.5 green tons/acre, respectively. Maple also had the second highest volume estimate (242.4 ft^3/acre). Unlike the weight estimates, however, yellow-poplar presented the third highest volume (161.2 ft^3/acre vs. miscellaneous hardwood species with 149.0 ft^3/acre). Cucumber trees had the lowest average volume, with 36.1 ft^3/acre remaining after harvest.

A total of 664 pieces of logging residue were measured on intensive lines. The average residue size was similar among species group (Fig. 1). Within the three sampled sites, the average small-end and large-end diameters of the pieces measured on intensive lines were 4.5 and 8.2 inches, respectively. The average length of all logging residue was 17.2 feet. The average small-end diameter was greatest in yellow-poplar (5.0 in.), followed by oak species (4.6 in.), cucumber (4.4 in.), maple (4.3 in.), and miscellaneous hardwoods (4.2 in.). Similarly, yellow-poplar and maple have the highest (8.8 in.) and smallest (7.8 in.) large-end diameter. Cucumber had the maximum average length (18.7 ft), followed by oak and maple (17.2 ft), miscellaneous hardwoods (16.3 ft), and yellow-poplar (16.2 ft).

Table 2.—Summary of diameter at breast height and merchantable height statistics by species group for trees sampled on surface mine sites in West Virginia.

	Diameter at breast height (in.)[a]				Merchantable height (ft)[b]			
Species group	*n*	Mean (SD)	Min	Max	*n*	Mean (SD)	Min	Max
Maple	458	6.6 (2.5)	4	20.5	164	27.1 (12.9)	4.5	69.9
Oak	173	8.8 (2.8)	4	16.9	68	39.1 (14.7)	16.0	78.1
Yellow-poplar	181	8.5 (3.4)	4	28.0	65	35.1 (16.6)	6.5	93.4
Cucumber tree	303	7.8 (2.4)	4	16.0	65	30.8 (12.1)	4.5	60.0
Miscellaneous hardwoods	379	7.6 (2.9)	4	21.0	107	30.3 (13.4)	4.0	61.8

[a] Breast height of 4.5 feet for all standing trees.

[b] Diameter to a 4-inch top diameter for standing trees on every third plot.

Table 4.—Average weights and volume of logging residue left after timber harvesting on surface mine sites in West Virginia.

	Weight (green tons/acre)		Volume (ft^3/acre)	
Species group	Mean	Max	Mean	Max
Maple	4.0	29.8	242.4	1,702.8
Oak	5.4	56.6	303.8	3,111.7
Yellow-poplar	2.0	18.4	161.2	1,474.6
Cucumber tree	0.5	9.5	36.1	692.7
Miscellaneous hardwoods	2.4	18.3	149.0	1,275.9

Based on the average of the three sites sampled, biomass availability per acre before grubbing operations was estimated to be 31.4 green tons/acre, including 17.0 (SD = 7.7) green tons/acre of standing trees and 14.4 (SD = 4.9) green tons/acre of logging residues. Because the sampling plots were randomly located within the three permit areas, they would represent the average conditions across each of the sites. When the estimated availability of 31.4 tons/acre is extrapolated to the surface mine permit area (835 acres), the total gross biomass stocks are 26,160.6 green tons.

Discussion and Conclusions

This study provides estimates for standing trees and logging residue that are available on surface mine sites during the secondary phase of fiber clearing in West Virginia. These results characterize roundwood remaining on site after traditional timber harvesting was completed and immediately before the site was released to surface mine operators. The timber operators that completed the original harvest had access to both sawlog and pulpwood markets in the region. Earlier research in the region of our study sites by Alderman and Luppold (2005) showed an average of 4.1 markets per logging operation. These sites were especially close to both hard- and soft-hardwood pulp markets for engineered products and paper pulp. While we do not have any data that show the remaining roundwood was substandard, we can hypothesize that market price and/or extraction cost was more limiting than actual fiber markets.

The estimated woody biomass availability reflects the expansion of the sampled surface mine conditions to those areas being mined during the 2010 to 2011 time frame. As the mine continues to operate, biomass resources will become available as the mine permit boundary expands, potentially creating new estimates of gross fiber availability. Although caution should be used in expanding this number to all active surface mines in West Virginia, a statewide estimate can be developed. From 2004 to 2008, a total of 56,402 acres were permitted in West Virginia. This estimate includes those acres undergoing incidental boundary revisions as well as other revisions that add acreage in addition to newly permitted mines (USDI OSM 2009). The overall average number of acres under development during this time was 11,280 and ranged from a high of 18,500 acres in 2004 to a low of 6,374 acres in 2005. Based on the estimates (31.4 green tons/acre) developed during our project, this would equate to 352,619 green tons of biomass. These estimates can be used to inform both mining operators and surface landowners about the potential gross biomass stocks that become available during these operations and, potentially, aid in the development of a means to utilize this fiber stream and reduce the costs associated with the clearing and disposal of these materials.

Many options are available to capture this waste stream and use the woody biomass in value-added opportunities. In West Virginia, timber harvesting is commonly accomplished by chain-saw felling, with delimbing and topping at the stump with chain saws and a substantial amount of logging residue remaining on site after timber harvesting (Wu et al. 2011). In more accessible areas, extraction machines, such as cable skidders or grapple skidders, can be used to collect the residues, which are more productive, possibly increasing the recovery rate of logging residue (Wang et al. 2004). While some may argue that the reason for the fiber remaining on site is the lack of markets, each of these sites were within trucking distance of several pulpwood markets, including both soft-hardwood pulp for oriented strandboard production as well as hard-hardwood pulp for paper. Likewise, the average small-end diameter, large-end diameter, and length of remaining residue easily

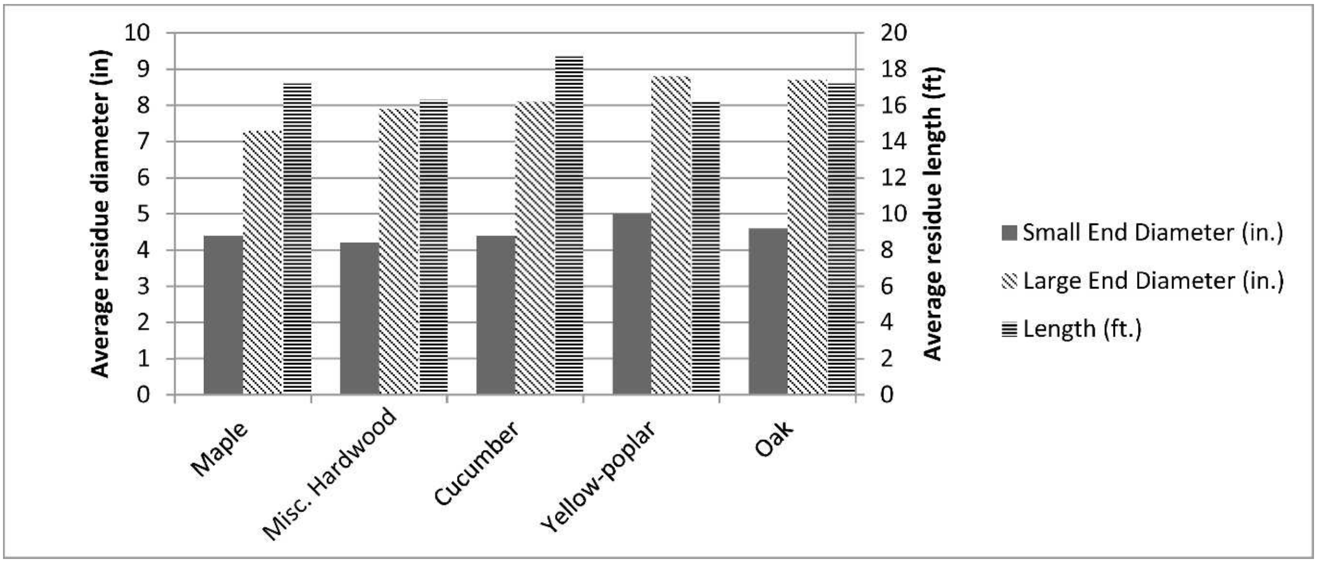

Figure 1.—Average logging residue piece size for each species group sampled on surface mine sites in West Virginia.

fell within the size restrictions for these markets. Thus, the volumes found in this study do not indicate lack of markets but, rather, that the cost to extract these residuals was greater than their value. Because of their size and quantity, the remaining standing trees and logging residues after surface mining operations represent a potential source of biomass feedstock, which could be used for biofuels production and would have the potential to improve the economic conditions in the communities where mining is occurring. Several options currently exist to blend biomass and coal to produce energy products. The co-combustion of biomass and coal represents a proven technology that can help reduce net CO_2, SO_x, and NO_x emissions and provide benefits to local communities (Baxter 2005). Likewise, through thermochemical conversion, coal and biomass blends can be used to produce synthetic liquid fuels, which can be developed at lower costs than existing cellulosic ethanol processes (Liu et al. 2011). To realize these new value steams, more information is needed on their gross volumes and how they might fit into the supply chain for existing traditional markets and/or new energy markets.

The gross availability of biomass during mine development was estimated in this study. These estimates can be used to develop new enterprises that focus on the biomass utilization for bioenergy. Coal mining has disturbed approximately 2.4 million hectares since 1930 in the United States (DeLong 2010) and will continue to represent a large portion of the US energy portfolio in the coming years. In West Virginia, large areas of formerly forested land are disturbed annually due to surface mining of coal (Townsend et al. 2009), and the potential use of the premining fiber resource has not been addressed. Developing industries on these sites that use this wood fiber as a feedstock also have the potential to increase the likelihood that short-rotation woody crops or natural forests are included in restoration plans. Although the vast majority of surface-mined sites in West Virginia were initially forested, they are rarely revegetated using trees. Surface mining of coal has been the primary mechanism in the conversion of forested lands in the region to grass and barren lands (Maxwell et al. 2012).

Many new reforestation efforts and technologies are being used to improve reforestation on mined lands. This is mainly due to both landowners and the public becoming aware of the societal and economic value of forests developed on these sites, especially the role they play in flood control, water quality, biodiversity, and carbon sequestration (Burger et al. 2004). The use of woody crops on surface mines has been investigated and, potentially, could supply wood fiber to energy systems after the coal is extracted. One fiber crop with potential is hybrid poplar, which is well suited for reforestation on mine lands in the Appalachian region (Casselman et al. 2006) and is a popular feedstock because of its available genome sequence, diverse adaptations, and quick growth characteristics (Yuan et al. 2008). During trials conducted in West Virginia, the volume yield of hybrid poplar on reclaimed surface mine sites was found to be greater than that of any other species tested (McGill et al. 2004). Moreover, active management appears to increase growth of hybrid poplar more than that of native hardwood mixtures (Casselman et al. 2006).

The estimation of gross biomass stock volumes that are currently being wasted in West Virginia is an important first step in the development of new opportunities in the coal fields of West Virginia and other Appalachian states. While these estimates reflect total gross biomass stocks, they do not reflect total availability. Total availability of this resource can be defined when production systems are identified that can be integrated with surface-mine clearing operations. In energy systems such as these, however, where a potential resource is being wasted, developments that increase the utilization of such materials would benefit the people and communities in the region both ecologically and economically.

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