Estimating volumes and costs of forest biomass in Western Montana using forest inventory and geospatial data

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Abstract

Utilizing timber harvest residues (biomass) for renewable energy production provides an alternative disposal method to onsite burning that may improve the economic viability of hazardous fuels treatments. Due to the relatively low value of biomass, accurate estimates of biomass volumes and costs of collection and delivery are essential if investment in renewable energy production is to occur. We have established a spatial framework for estimating biomass volumes and costs of availability using publicly available data and models for Ravalli County in Western Montana. We used forest inventory data to estimate forest conditions and remotely sensed data to identify lands suitable for treatment and the spatial distribution of biomass resources. Using our framework, we geographically identified approximately 67,000 acres of low elevation, frequent fire interval forestland potentially available for fuel reduction treatment. Our analysis of forest inventory data shows that if a comprehensive forest restoration treatment is applied to these selected forestlands, 12 to 14 green tons per acre of biomass are potentially available for energy production in Ravalli County, Montana, at reasonable delivered costs.

The potential for timber harvest residues (biomass) available from forest health treatments to contribute to renewable energy production throughout the inland western United States is considerable. Currently in Montana there are approximately 7.5 million acres of frequent fire interval forestlands potentially available for forest health or fuel reduction treatments (Fiedler et al. 2004). These forests are characterized as having a moderate to high crown fire hazard rating (Fiedler et al. 2004), excessive fuels, stagnation, and other factors that encourage disease and insects (Leenhouts 1998, Fiedler et al. 2001). Mechanical fuel reduction treatments in these forests would result in significant volumes of biomass not suitable for timber or pulp markets that must be disposed of. Unfortunately, many areas of the inland west, where there exist vast resources of biomass, lack renewable energy markets so biomass is typically disposed of by burning at the treatment site.

Hazardous fuel reduction and forest restoration treatments provide land managers the ability to mechanically return low elevation fire adapted forests in the inland west to sustainable conditions. These treatments have the potential to produce significant quantities of biomass that must be removed in order to accomplish the treatment objectives. Traditionally, this biomass has been disposed of onsite by burning, which has drawbacks such as potential escape, air quality issues, and limited burning windows. Renewable energy production provides an alternative biomass disposal method that could increase the economic returns of treatments designed to reduce fire hazard. However, renewable energy production markets are not likely to emerge unless a clear understanding of feedstock supplies and costs are available. This study provides a framework to estimate biomass resources in a specified location, their geographical distribution, and associated costs of availability.

Biomass volume and cost estimates across large areas have typically been coarse averages (Walsh et al. 2000, Fried et al. 2003, USDA 2003a). For example, FIA BioSum (Fried et al. 2003) was developed to identify "hotspots" of biomass sup-

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ply, compare fuel treatments, and estimate harvest and haul costs to hypothesized energy production facilities for very large areas. In doing so, FIA BioSum relies on Forest Inventory and Analysis (FIA) and USDA Forest Service Region 6 expansion factors, which average approximately 6,000 acres, to estimate total potential biomass for energy from fuel reduction treatments. As Chalmers et al. (2003) note, FIA small tree sampling intensity is less than 0.0003 percent in areas this size, and while the quality of data for small trees is excellent, the quantity is poor. Han et al. (2002) produced biomass estimates for southwest Idaho but the study relies on industry-wide log-residue relationships derived from harvested logs only. Other studies have examined only fuel reduction treatment costs (Fiedler et al. 1999, 2001, 2004; Larson et al. 2000) and do not provide biomass volumes made available from these treatments.

In this study, we have taken an alternative approach for estimating biomass available for renewable energy production from fuel reduction treatments. We estimate biomass volumes available from selected forest types in a western Montana county and the spatial distribution of the biomass resources. Our spatially oriented framework was derived using remotely sensed data to expand ground-sampled forest inventory data. Remotely sensed data are aerially photographed or satellite imaged, and mapped at varying resolutions. These data provide landscape attribute information such as cover type (e.g., urban, forest, water, rock), forest/non-forest status, and if forested, canopy coverage and stand-level tree diameter classification. We believe if attributes from ground-sampled forest inventory data are related to like attributes of remotely sensed data, at a large enough scale, biomass estimates will be more rigorous than those derived from FIA expansion factors alone. Utilizing the strengths of both, FIA data and remotely sensed data thus serve to complement each other in this application.

Along with biomass volumes we estimated associated costs of availability that include felling, bucking, skidding, and hauling—all the costs of stump-to-mill log production. To do this, we integrated a scientifically based fuel reduction/forest health silvicultural treatment with ground-sampled forest inventory data and a geographic information system (GIS). This framework was derived to geographically identify and quantify sources of biomass for renewable energy production from federal and private forestlands and to estimate associated costs of availability. The cost and volume estimates were derived with an existing biomass energy production facility in mind. Realistic stump-to-market volume and cost estimates for biomass feedstocks are essential for determining the feasibility of potential energy production industries, and this study provides a framework for determining volumes and costs applicable in any region where similar data are available. While feasibility studies are conducted with specific end-use locations in mind, our framework allows for the specification of any number of end-use locations. And while we apply our framework to a selected renewable energy production location, this methodology is not limited to our selected site.

Methods

Our approach to estimating biomass volumes and costs consisted of five steps: 1) evaluating existing forest conditions from selected forest inventory data to identify plots in low elevation frequent fire interval areas; 2) modeling the application of a silvicultural prescription with the forest inventory data and producing a cut tree list; 3) estimating harvest costs for the cut tree list using two harvest systems; 4) identifying lands eligible for the prescription using remotely sensed data based on forest type, ownership, fire regime condition class, slope, and proximity to existing roads; and 5) developing haul cost estimates using GIS road network layers. **Figure 1** shows the flow of data through our analysis framework. This framework was used to produce estimates of biomass stock availability, and costs of availability for a specified location.

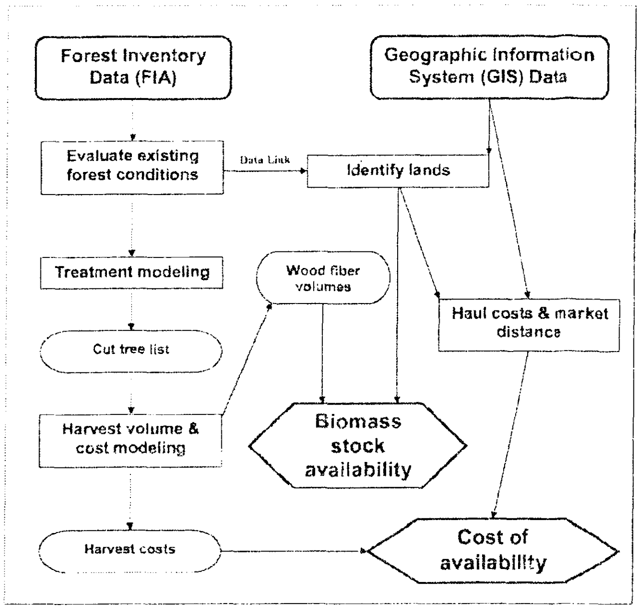

Figure 1. — Data flow through analysis framework.

Study area

The area of concern for this analysis—the Bitterroot Valley in Ravalli County, Montana—was selected because it has a number of factors that make biomass energy production attractive. However, it is far from unique in terms of communities in the inland western United States. The area has an abundance of National Forest land (~70%), a growing population particularly in the Wildland Urban Interface (WUI), a significant amount of low elevation forestland in need of treatment (> 67,000 acres, Loeffler 2004), experienced a severe wildfire season in 2000, and is within proximal distance of a modest amount of existing wood products infrastructure. These facilities include two recently established, small-scale plants within the study area capable of utilizing biomass for thermal energy and a sawmill and pulpmill in the adjoining county to the north (**Fig. 2**).

Evaluating existing forest conditions

Ground-sampled forest inventory data were used to estimate current forest conditions. FIA data acquired from the USDA Forest Service Research Forest Inventory and Analysis National Program Online Database Retrieval System (http://fia.fs.fed.us) were used to estimate forest stand conditions in the area. For each inventory plot "several observations are recorded for each sample tree, including its diameter, species, and other measurements that enable the prediction of the tree's volume, growth rate, and quality" (Alerich et al. 2004).

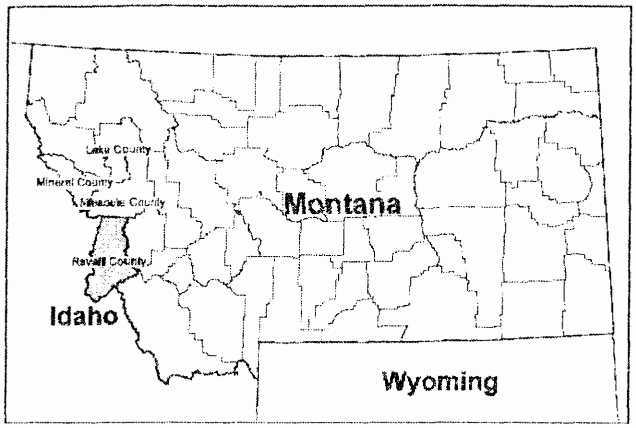

Figure 2. — Study area: Ravalli County, Montana.

In an effort to decrease bias in the estimates, and increase estimate consistency, FIA plots selected for analysis were expanded beyond Ravalli County to include three additional contiguous Montana counties (Lake, Mineral, and Missoula) (**Fig. 2**). These counties have forest types and forest conditions similar to those found in Ravalli County (Fiedler 2003). FIA plots were initially selected based upon the forest types for which the selected forest restoration prescription was designed: lower elevation ponderosa pine (PP), Douglas-fir (DF), and a non-majoral mix of predominantly ponderosa pine, Douglas-fir, and western larch, called dry lower mixed conifer (DLMC). Subsequent to isolating plots of these forest types, FIA plots were further restricted to plots on National Forest and private lands categorized as fire regime condition class 2 or 3. Briefly defined, "fire-regime condition class (FRCC) is an approximation of ecosystem departure resulting from a change in fire regimes" (USDA 2003b). FRCC 2 and 3 represent the most substantial departure from historic fire regime. Lands with these types of ownership and fire hazard rating are the best candidates for receiving fuel reduction treatment.

Modeling a silvicultural treatment

The prescription selected for this analysis was designed to restore lower elevation frequent fire interval forests in the inland west to historical and sustainable conditions (Fiedler et al. 1999, 2003). Cut tree lists were developed by applying Fielder's prescription to the selected FIA plots. Plots that either had no harvest activity or were extreme outliers were removed, reducing the final data set to 100 FIA plots. Statistics from the cut tree lists were summarized across three quadratic mean diameter (QMD) classes: less than 5 inches, 5 to 9 inches, and greater than 9 inches (**Table 1**). The large standard deviations indicate high variability across the FIA plots, reflecting the sheer variety of stand conditions present at the time of sampling. Examination of two measures of central tendency, mean and median, indicate that the distributions of trees in each of the classes are skewed toward the larger trees in each class, except for the QMDs of cut trees less than 9 inches, which are skewed toward smaller trees. These statistics from the FIA plots were created to take forward into the harvest cost model. Furthermore, we assume that mean biomass estimates conservatively represent current biomass availability in the study area, since fuels reduction programs are likely to prioritize treating the more heavily stocked stands first.

Table 1. — Summary statistics of the cut tree list (n = 100).

Variable	Mean	Median	SD[a]
Trees per acre cut <5 inches	176.0	60.0	248.88
Trees per acre cut 5 to 9 inches	75.5	53.6	78.77
Trees per acre cut >9 inches	56.5	48.5	42.07
QMD of trees <5 inches	1.9	2.1	1.53
QMD of trees 5 to 9 inches	5.0	6.8	2.64
QMD of trees >9 inches	12.9	12.5	3.48
Cubic foot volume per acre <5 inches	90.4	33.2	168.45
Cubic foot volume per acre 5 to 9 inches	353.3	236.0	388.50
Cubic foot volume per acre >9 inches	1,145.5	898.0	918.60

[a] SD = standard deviation.

Modeling biomass volumes and harvest costs

The harvest volume and cost model selected for this study—the Fuel Reduction Cost Simulator (FRCS) (Fight et al. 2003, Hartsough and Fight 2003)—requires few input variables and minimal timber harvest operational knowledge. The model allows cost comparisons for up to six harvest systems; for this analysis we have specified whole tree (WT) and cut-to-length (CTL) because they represent the most common ground-based systems in the study area. Required FRCS input variables include trees per acre removed, QMD, average tree volume, green wood weight, and residue weight to bole weight fractions. The latter were calculated from the summarized cut tree list, and regression equations and green wood weights provided by Brown (1978). We used the average slope of 22 percent for lands identified as suitable for treatment through GIS analysis and assumed wood fiber moisture content of 50 percent. Three skidding/forwarding distances (300, 800, and 1,300 ft) were specified to represent varying average harvest site distances from the nearest road. We used the model's default residue recovery fractions of 0.80 for WT systems and 0.65 for CTL systems. The residue recovery fraction represents the actual amount of biomass collected and removed from the site. The model was calibrated to reflect Western Montana wage rates: $24.60/hr for fallers and/or buckers and $16.13/hr for all others (2002 dollars) (ACINET 2003). The model's default labor benefit rate of 35 percent was retained and move-in costs were not included. Using the FRCS model and variables calculated from the summarized cut tree list, biomass volumes and harvest costs were estimated for each FIA plot for the three skidding distances. Average costs were then computed for each harvest system and skidding distance from the list of FIA plots.

Identifying eligible lands

GIS is often used to identify, assess, and evaluate any number of research issues based on landscape feature data recorded from remote sensing (i.e., satellite imagery, aerial photography) and/or field collection. The use of remotely sensed data and GIS analysis in this framework allowed us to identify lands that were deemed appropriate for the selected silvicultural treatment based on cover type, FRCC, proximity to roads, slope, ownership, and wildfire occurrence.

The forest conditions, or cover type, of each polygon in the spatial data had previously been categorized (Chew et al. 2004) using vegetation attributes of the Satellite Imagery Land Cover Classification (SILC 1) data (Redmond 1996), and were supplied by the Bitterroot National Forest. The FIA plots were matched with these GIS data by cover/forest type

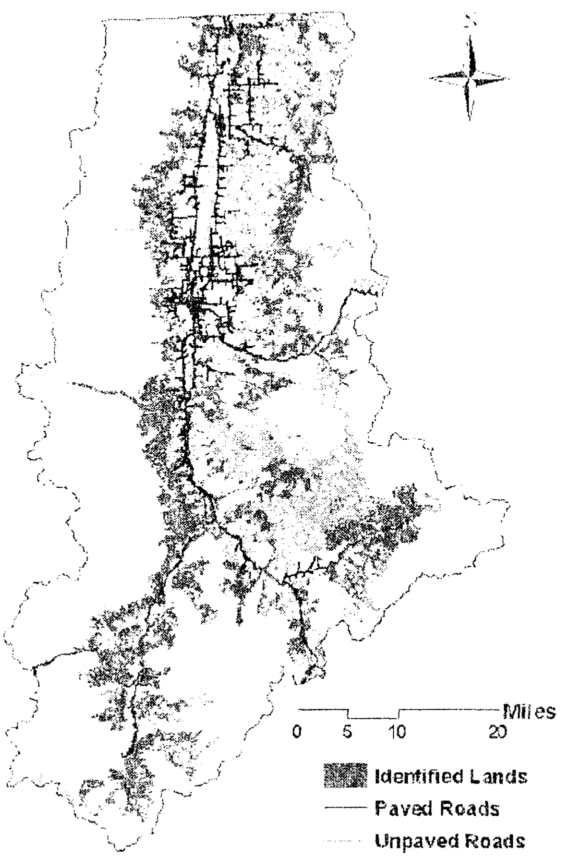

Figure 3. — Composite map of lands and roads in Ravalli County, Montana.

yielding a data link between the two data sets. Only lands having cover types of DF, PP, or DLMC were retained for analysis. Slope was determined using the appropriate U.S. Geological Survey Digital Elevation Model and the Spatial Analyst tool within the GIS software. Only lands with slopes less than or equal to 35 percent were evaluated based on the requirements of the two ground-based harvest systems selected for analysis. Land ownership was limited to National Forest and private forestland as recorded by the Montana Cadastral Mapping Project of the Montana Natural Resource Information System (NRIS 2004). Additionally, lands categorized as FRCC 2 or 3 were retained based upon a 90-m GIS data layer obtained from the USDA Forest Service Northern Region National Fire Plan Cohesive Strategy Geospatial Database (USDA 2003b). Finally, we excluded lands that experienced high or medium burn severity in the 2000 wildfires, using data supplied by Bitterroot National Forest staff. **Figure 3** shows the location of the lands selected for analysis.

Estimating haul costs

Prior to widespread use of GIS, haul costs had been simplified by incorporating fixed distance cost estimates into total mill delivered costs (Han et al. 2002, Keegan et al. 2003, USDA 2003a). However, a significant portion of the delivered cost of biomass can be due to transportation (Han et al. 2002, USDA 2003a). Therefore, to develop accurate estimates of haul costs, we calculated the distance in miles by road surface type from each polygon to the identified biomass energy production facility. We then assigned a per-mile haul cost based upon the surface type of road traveled. This approach was selected because log trucks and chip trucks/vans travel at different rates of speed depending on the road's surface type. Two haul cost estimates were obtained from a Forest Service Region 1 stewardship contract awarded in 2002 (USDA 2003c): $2.28 per mile per loaded truck for paved roads and $4.68 per mile per loaded truck for unpaved roads. Using these costs and assuming a 15-ton chip van, average costs would equal $.15 per mile per ton for paved roads, and $.31 per mile per ton for unpaved roads.

The primary road data used in this analysis for lands outside the Bitterroot National Forest were downloaded from the Montana NRIS (NRIS 2004) and contained existing roads in Ravalli County. The road layer did not, however, contain surface type information. In a process of data aggregation, GIS and landscape level data from a total of four sources (Montana Natural Resource Information System, Bitterroot National Forest, Montana Department of Transportation, and Ravalli County Department of Transportation) were combined to form the road layer with surface types used for this analysis. **Figure 3** shows the composite map of selected lands and roads.

For purposes of this study, we assumed biomass is delivered to an existing thermal energy production facility located in the southern portion of Ravalli County in the town of Darby. The least cost route from all polygons to Darby was determined by converting the road layer to a raster grid of 30-m cells. Each cell was then assigned a value equivalent to the haul cost of travel along a paved road, a unpaved road, or infinite cost where no roads occurred. The least cost route from each cell to Darby was then calculated using the cost weighted distance function of the Spatial Analyst tool in the GIS software. This provided the least haul cost from each polygon along the entire road network to Darby. These costs were then assigned to adjacent stand polygons not directly located on a road.

Framework output: estimating biomass volumes and costs of availability

Biomass volumes were estimated using the FRCS volume and harvest cost model using cut tree list variables produced from the silvicultural treatment. Mean estimates for both harvest systems were then computed from the 100 FIA plots. Biomass costs of availability were estimated by summing the average stump-to-loaded-truck cost estimates for each harvest system with haul costs from each polygon in the study area. Equation [1] identifies the delivered cost per green ton of biomass for a specific polygon for the two harvest systems and three average skidding/forwarding distances:

$$Y_{i,sys,fwd} = \overline{H}_{sys,fwd} + r_{unpav} \times dist_{i,unpav} + r_{pav} \times dist_{i,pav} \qquad [1]$$

where $Y_{i,sys,fwd}$ = delivered cost per green ton of biomass collected from polygon i for the system sys (CTL or WT) and skidding/forwarding distance fwd (300, 800, or 1,300 ft); $\overline{H}_{sys,fwd}$ = average cost per green ton of collecting biomass (chipping costs only for WT; for CTL, costs include slash bundling, forwarding, and loading based on fwd distance); r_{unpav} = per-ton haul cost on unpaved roads; $dist_{i,unpav}$ = distance (mi) on unpaved roads from polygon i to Darby; r_{pav} = per-ton haul cost on paved roads; $dist_{i,pav}$ = distance on paved roads from polygon i to Darby. Using polygon size in acres as

Table 2. — Mean per-acre stump-to-mill treatment costs (harvest and haul) with and without biomass collection, by harvest system and skidding/forwarding distance.

	Whole tree			Cut-to-length		
Skid forward distance	300	800	1,300	300	800	1,300
Without biomass[a] ($/acre)	1,494	1,654	1,795	1,803	1,852	1,908
Minimum standard error[b]	69.90	79.91	88.49	95.81	98.41	101.28
With biomass ($/acre)	1,450	1,610	1,751	1,977	2,039	2,106
Minimum standard error	72.06	82.09	90.68	109.65	113.00	116.62
Difference (Without − With)[c] ($/acre)	−44	−44	−44	174	187	198
Average delivered cost per ton[c] ($)	−3	−3	−3	15	16	17

[a] Includes onsite burning costs ($174 per acre).

[b] Does not include onsite burning cost error estimates.

[c] Negative value indicates revenue in excess of cost.

a weighting method, average delivered cost per green ton for the study area is defined as:

$$\overline{Y}_{sys,fwd} = \overline{H}_{sys,fwd} + \sum_{i=1}^{n}\left[\frac{acres_i\,(r_{unpav} \times dist_{i,unpav} + r_{pav} \times dist_{i,pav})}{\sum_{i=1}^{n} acres_i}\right] \qquad [2]$$

where $\overline{Y}_{sys,fwd}$ = average delivered cost of biomass per green ton in the study area; *acresi* = size of polygon *i*; *n* = all polygons meeting the treatment requirements.

Results

In order to accomplish the fuel reduction objectives of the prescription, biomass must be treated onsite or, alternatively, removed from the site. If biomass is not physically removed, the most likely alternative disposal method is onsite burning. For the disposal tradeoff analysis, we assumed an average USDA Forest Service Region 1 burning cost of $174 per acre (Cleaves et al. 2000). Therefore, the marginal cost of biomass availability is defined as the difference between harvest costs with biomass removal including haul costs, and harvest costs without biomass removal including the $174 per acre onsite burning cost. Per-acre stump-to-mill costs are shown in **Table 2**. Because the prescription removes trees greater than 5 inches diameter at breast height (DBH), costs shown in **Table 2** also include haul costs of harvested merchantable materials (> 5 in DBH) to a sawmill and a pulpmill in Missoula County, Montana. We found that, on average, it costs $3 per ton more to burn biomass onsite than to chip it at the landing and haul it to Darby using a WT system. Conversely, using a CTL system biomass costs $15 to $17 per ton more to slash bundle, forward, load, and haul to Darby than onsite burning. The sizable difference in cost per ton between the two harvest systems is attributable primarily to the location of the biomass after the treatment is complete. However, it is important to note that burning costs can be highly variable. In locations where burning costs are $130 or less per acre, it would be more expensive to collect and deliver biomass using a WT system than onsite burning.

The FIA plots have shown that implementing the selected prescription in the study area using a WT system results in approximately 14 green tons per acre of biomass at 50 percent moisture content while a CTL system would yield approximately 12 green tons per acre of biomass (**Table 3**). There were just over 67,000 acres identified via GIS that were suitable for the prescription, resulting in a total biomass stock availability of approximately 940,000 green tons using a WT system and 806,000 green tons if a CTL system is used. Static biomass supply in Ravalli County, Montana, for both harvest systems is shown in **Figures 4** and **5**. With a WT system, most of the biomass is deliverable to Darby at costs less than the alternative burning disposal method. Using a CTL system, most of the biomass is available for a cost less than $20 per green ton. Including additional forest types in the study area would identify more sources of biomass; however, there is reasonable potential for delivered costs to exceed those included within these figures, as distance from Darby increases.

Discussion

Estimates of biomass volumes on small or large scales using spatial data should result in more accurate estimates than FIA expansion factors alone. Remotely sensed data are ideally suited for identifying potential forestlands in need of fuel reduction treatments. However, in our analysis, the assumption that average biomass volumes tallied from FIA data can be applied to all lands identified using the GIS methodology must be made with caution. We believe further examination of crown cover and/or size class relationships, both of which are available in the two data sets, may provide a better means to determine the proportion of lands identified via GIS to which the FIA estimates could be applied. Additionally, remote sensing technology is advancing, and has already surpassed that available at the time of this analysis. For example, the Northern Region Vegetation Mapping Project (R1-VMP) has addressed problems identified in the SILC data (Brewer et al. 2004). As a result, the expected accuracy of the R1-VMP data, which was not available at the time of this analysis, has increased substantially for dominance type (cover type) beyond the SILC data.

Furthermore, our estimates are based on several key assumptions. First, we assumed the forest conditions found in the inventory data represent current conditions on the ground. Second, all lands identified via GIS using the selection criteria would be treated using our selected silvicultural treatment, and will yield the average amount of biomass calculated from the FIA data. Third, a regional average onsite slash disposal cost of $174 per acre applies to all lands where biomass is not collected. Fourth, the static supply curves presented in **Figures 4** and **5** assume acres will be treated in order of ascending cost. Fifth, biomass removal and delivery to the energy production facility is always an alternative to onsite burning. Sixth, haul costs are based on truck operating cost per mile, and lastly, biomass removal (chipping and hauling) occurs at the time of treatment.

In this study, we have shown that large-scale forest inventory data can be applied to small geographic areas, resulting in robust estimates of biomass potentially available for renewable energy production. Our framework also provides stake-

Table 3. — Treatable acres and total biomass available by harvest system (n = 100).

	Whole tree	Cut-to-length
Study area (acres)	67,187	67,187
Green biomass (tons/acre)	14	12
Total biomass (green tons)	940,618	806,244

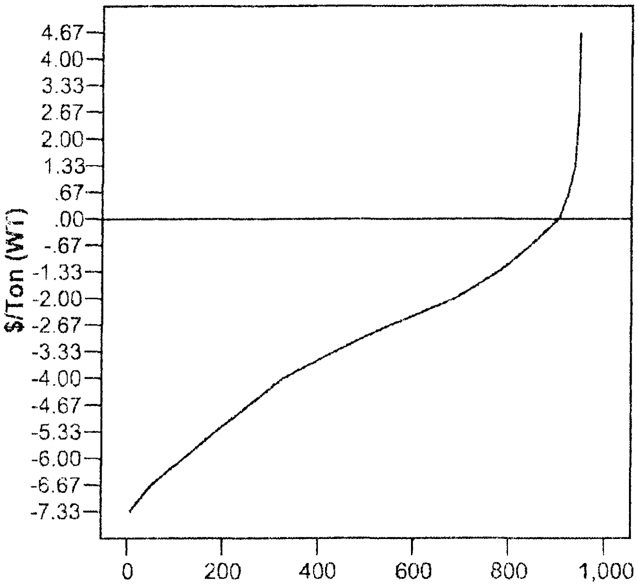

Figure 4. — Static biomass supply using a WT system. Negative values indicate revenue in excess of cost.

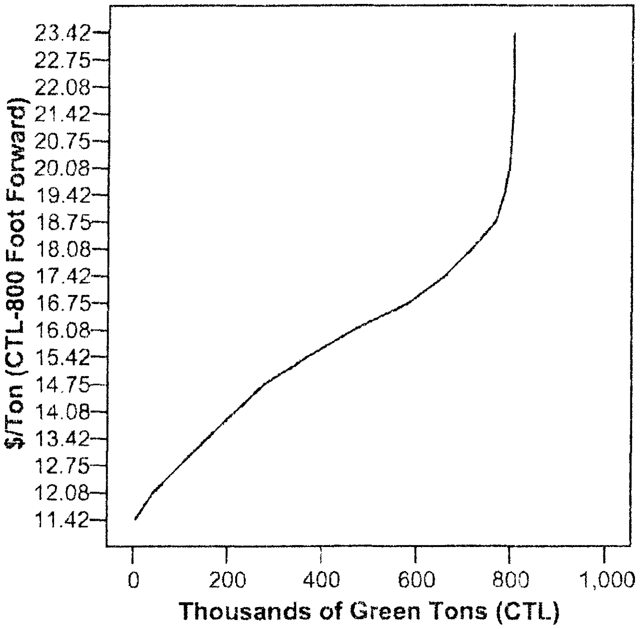

Figure 5. — Static biomass supply using a CTL system.

holders with a cost-effective methodology for estimating biomass feedstock resources as well as their spatial distribution. Because biomass is a low-value product characterized by high collection and haul costs, these types of assessments are essential to determine potential feasibility of energy production industries. These results are believed to provide landscape level biomass estimates at a high degree of accuracy, not only providing stakeholders with valuable information on "how much," but also "where" and "at what cost."

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