Biomass Resources, Uses, and Opportunities in West Virginia

Jingxin Wang
Shawn Grushecky
Joe McNeel

West Virginia University
Biomaterials and Wood Utilization Research Center
Division of Forestry and Natural Resources
Morgantown, WV 26506
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Biomaterials Center
West Virginia University
Division of Forestry and Natural Resources
Morgantown, WV 26506
jxwang@wvu.edu
(304) 293 2941 x.2481

West Virginia Development Office
Energy Efficiency Program
Capitol Complex, Building 6
Charleston, WV 25305-0311
jherholdt@wvdo.org
(304) 558 0350

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EXECUTIVE SUMMARY

West Virginia, located in the central Appalachian region, has abundant biomass resources. The state of West Virginia is the third most heavily forested state in the U.S. and has 12 million acres of forest land (USDA 2000b, Griffith and Widmann 2003). West Virginia also has 3.6 million acres of farmland (USDA/NASS 2006).

The state produces 2.41 million dry tons of wood residues per year including 1.34 million dry tons of logging residue, 941,868 dry tons of mill residues, 118,590 dry tons of urban tree residues and 12,716 dry tons of pallet residues. The state’s annual agriculture residue production is 903,826 dry tons including 101,000 dry tons of grass seed residue, 10,618 dry tons of corn stover, 131,440 dry tons of corn silage, 1,585 dry tons of soybean residue, 3,731 dry tons of all wheat straw, 3,838 dry tons of switchgrass, 2,593 dry tons of short rotation woody crop, 662,780 dry tons of animal manure, and 26,241 dry tons of solid wood material from the construction and demolition waste.

The total annual biomass production potential is 3.32 million dry tons in West Virginia (Figure ES.1, Table ES.1), which could produce 47.06 trillion BTUs. The forestry sector produces 72.7% of the total residue biomass in the state while the agriculture sector provides the rest of 27.3%.

![Figure ES.1 Annual biomass resource potential in West Virginia.](image)

A small portion of logging residues is used for firewood or other purposes in West Virginia. However, there are no statistical data to indicate the amount of logging residues being used annually for these purposes. There is a growing interest in more efficient utilization of logging residues and conversion of these underutilized materials to bioproducts or bioenergy.

The demand/supply ratio (or utilization rate) of mill residue averaged 38% during 1999 and 2005, and it increased to 68% recently. The weekly demand for mill residue averaged 8,025 dry tons over the last seven years, among which 62.8% was for sawdust, 31.8% was for chips, and 6.2% was for bark.
Table ES.1 Summary of annual biomass production potential in West Virginia.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Biomass production (dry tons)</th>
<th>BTUs per pound(^1)</th>
<th>Total BTUs (10(^{12}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood residues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logging residue</td>
<td>1,340,000</td>
<td>7,500</td>
<td>20.00</td>
</tr>
<tr>
<td>Mill residue</td>
<td>941,868</td>
<td>7,500</td>
<td>14.13</td>
</tr>
<tr>
<td>Urban tree residue</td>
<td>118,590</td>
<td>7,000</td>
<td>1.66</td>
</tr>
<tr>
<td>Pallet residue</td>
<td>12,716</td>
<td>7,000</td>
<td>0.18</td>
</tr>
<tr>
<td>Subtotal</td>
<td>2,413,174</td>
<td></td>
<td>36.07</td>
</tr>
<tr>
<td>Agriculture residues</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass seed residue</td>
<td>101,000</td>
<td>6,000</td>
<td>1.21</td>
</tr>
<tr>
<td>Corn stover</td>
<td>10,618</td>
<td>6,300</td>
<td>0.13</td>
</tr>
<tr>
<td>Corn silage</td>
<td>131,440</td>
<td>6,300</td>
<td>1.66</td>
</tr>
<tr>
<td>Soybean residue</td>
<td>1,585</td>
<td>6,300</td>
<td>0.02</td>
</tr>
<tr>
<td>All wheat straw</td>
<td>3,731</td>
<td>6,100</td>
<td>0.05</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>3,838</td>
<td>7,000</td>
<td>0.05</td>
</tr>
<tr>
<td>Short rotation woody</td>
<td>2,593</td>
<td>7,000</td>
<td>0.04</td>
</tr>
<tr>
<td>crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal manure</td>
<td>622,780</td>
<td>6,000</td>
<td>7.47</td>
</tr>
<tr>
<td>C&amp;D residue</td>
<td>26,241</td>
<td>7,000</td>
<td>0.37</td>
</tr>
<tr>
<td>Subtotal</td>
<td>903,826</td>
<td>27.3</td>
<td>10.99</td>
</tr>
<tr>
<td>Grand total</td>
<td>3,317,000</td>
<td></td>
<td>47.06</td>
</tr>
</tbody>
</table>


The primary uses of mill residues have changed over time in West Virginia. Mill residues were used mainly for boiler fuel (65.7%) in 1999 and then decreased gradually to 33.6% in 2002 and to 17.5% in 2005. Mill residues for mulch averaged 15.5% each year. Mill residues for pellet fuel have steadily increased. Specifically in 2005, pellet fuel was the major use of mill residues and accounted for 66.7% of the total. It was followed by boiler fuel (17.5%) and mulch (8.6%). It was noticed that 7.2% of mill residues were also used for composite materials in 2005.

There are no data to support how many dry tons of corn residue, grass seed residue, wheat straw, and soybean residue are used for biofuels in the state. Of all the chicken litter producers in West Virginia, 33% used all of their litter, 52% used some and 15% used none of it. For the on-farm litter utilization, the greatest percentage of litter was used as fertilizer (91%) and only 8% was used for feed supplement. For the litter used for fertilizer, an average of 82% was reported for use on grassland and 16% was used on row crops. Among the litter producers, 60% of them sold 76-100% of their litter as fertilizer. Some research has been conducted for converting hog manure to biofuel (Eddy 2006). However, effective utilization of animal manure needs to be emphasized in the state.

Wood and agricultural residues are the major biomass resources in West Virginia. In 2001, the state of West Virginia consumed 1,255 trillion BTUs of energy, among which only 1% was produced from biomass (EIA 2006). With the biomass resource, West Virginia has the potential to produce 5.4 billion kWh of electricity from biomass, which is enough to supply power to 543,000 average homes, or 61% of the state’s residential needs (McCann 2005). We
are facing a unique challenge to efficiently use West Virginia’s abundant biomass to produce bioenergy and bioproducts, and to promote the state’s economy as well. Certainly, we have better opportunities to utilize the state’s biomass resources in a sustainable and environmental-oriented manner. The utilization of biomass for pellet fuels, engineered value-added or other bioproducts should be our major focus in the state. Biofuels or bioenergy conversion from renewable biomass would provide West Virginia a significant opportunity in economic development and energy independence.
1. INTRODUCTION

The reliability of traditional modes of forest resource extraction to generate economic income for forest owners has been reduced by strict environmental regulations, increased transportation costs, a weak global economy, and competition from global markets (Vogt et al. 2005). On the other hand, increased concern about energy security has fueled interest in using biomass feedstock to produce bioenergy and bioproducts. Oil imports and costs have climbed to record high oil trading at approximately $70 per barrel in August 2006. Approximately 58% of our current oil use is imported, 20% of which comes from the Persian Gulf (Stokes 2006). At the same time, wood energy use in the United States is projected to increase 39% by the year 2040 (Skog and Rosen 1997). Benefits of using biomass as feedstocks for bioenergy include reduction of the use of nonrenewable fuels, less dependency on foreign fuels, stabilization of income in rural areas, and reduced carbon dioxide emissions to the atmosphere (Office of Technology Assessment 1993). Furthermore, linking biomass collection and transportation to economically generate raw material for bioenergy can create new, high-skilled jobs for people specializing in engineering systems, computers, economics, and international trade while providing new opportunities for forest managers, biologists, and engineers (Vogt et al. 2005).

Biomass, composed of a wide variety of forest and agricultural resources (Figure 1.1), is identified as the only current renewable source of liquid transportation fuel (Perlack et al. 2005). Forest-derived biomass includes residues produced during harvesting of forest products, fuel wood extracted from forestlands, residues generated at primary and secondary wood processing facilities, and biomass from fuel treatments. According to reports by the United States Environmental Protection Agency (USEPA), wood and wood fiber products (including paper and paper-based products) are the largest component of the municipal waste stream in the United States, and accounted for more than 60% of total municipal solid wastes generated in the U.S. (USEPA 1997). Agricultural resources include grains used for biofuels production, animal manures and wastes, and crop residues derived primarily from corn and small grains (ORNL 2005).

Perlack et al. (2005) summarized biomass production and availability in the United States. They reported that 107 million dry tons of wood residues are produced annually from primary and secondary wood processing mills. Logging residue (49 million dry tons) and other removals (18 million dry tons) totaled nearly 67 million dry tons annually. A similar report summarized the geographic perspective on the current biomass resource availability in the U.S. (Milbrandt 2005). Due to ownership patterns, most logging residues were produced on privately owned lands. However, many factors limit the accessibility to and utilization of these wood residues including technical, market, and cost barriers. One of the biggest concerns associated with logging residue is the costs of collecting, trucking, and processing. Although the transportation technology is available for nearly any type of terrain even without roads, economic and political constraints usually inhibit working in roadless or areas with rugged terrain. The recoverability of wood for bioenergy and biobased products is a function of tree form, technology, and timing of the removal of the biomass from the woods. The recoverability could be more than 90% if an integrated system was used for biomass harvesting and processing (Perlack et al. 2005). They also reported that the annual harvest in the United States is less than the annual forest growth and considerably less than the total forest inventory. It suggests a substantial scope for expanding biomass resources for bioenergy.
West Virginia is one of the most heavily forested states. A large quantity of wood residues are produced by the primary and secondary wood products industries in West Virginia on a weekly basis, most in the form of bark, chips, and sawdust. Likewise, during the timbering process, logging residues are left on the ground after harvest. The state also produces a significant tonnage of agricultural residues each year.

Although wood residues being produced by primary and secondary wood products industries are being utilized for pulp chips, composite production, and fuel for energy production, a significant amount of wood residues enters the waste stream, thus rendering these underutilized renewable natural resources seems necessary (Alderman 1998). Even with this significant and low cost resource, no large-scale commercial facility is currently operating in the state and new opportunities for the development and adaptation of technologies have been limited due to a lack of solid economic and business related information. To date, very little of this “waste” is ever utilized for energy or to create new or value added products. To expand the productivity and viability of the forest products and agriculture sectors, new uses and products focused on residue biomass are critically needed.

There is considerable data available on the woody biomass quantities in West Virginia. These data can help interested parties make decisions about developing new industries that use these resources. However, West Virginia manufacturers have limited information on potentials/markets for biomass serving as feedstock of bioenergy. An understanding of the factors that affect the production and utilization of biomass in West Virginia is critical to maximizing the economic values of these renewable resources, improving the West Virginia’s economy, providing a significant opportunity for the state.
2. BIOMASS RESOURCE INVENTORY

2.1 Resource Identification

West Virginia has a total of 12 million acres of forestlands or 78% of the state with over 260,000 forest landowners (USDA 2000b, Griffith and Widmann 2003). Ninety-eight percent of the forestlands are timberlands, which is land capable of growing more than 20 ft³/acre/year of wood at culmination of mean annual increment (USDA 2000b). Among the total timberlands in West Virginia, 79% are privately owned, 9% forest industry owned, 8% are national forest, and 4% are owned by other public (Figure 2.1). The timberlands in West Virginia produce 23,200 million cubit feet of volume (for all live trees 5 inches diameter at breast height and larger) or 804 million dry tons of biomass (Miles 2006). Forest lands spread throughout the entire state of West Virginia while McDowell and Webster are the most heavily forested counties with 93% of forest coverage (Figure 2.2).

Forest industry is the only natural resource industry present in all 55 West Virginia counties and its economic impact exceeds $4.0 billion annually to the state economy (Childs 2005) (Figure 2.3). Employment in wood products and furniture industries rose from 6,500 in 1980 to 11,800 in 2004 (Childs 2005). The sawmills in the state could produce 700 to 800 million board feet annually.
Figure 2.2 Percentage of forest land in West Virginia by county. (Source: USDA 2000b)

Figure 2.3 Locations and type of forest industry in West Virginia.
There were 20,800 farms reported in West Virginia in 2005 (USDA/NASS 2006). These farms made up 3,600,000 acres, while the average size of each farm was 173 acres. Operations containing hogs and pigs totaled 800. Sheep and lamb operations totaled 1,000. The cattle inventory for 2005 totaled 410,000 head. There were 195,000 calves during 2005. The hog and pig inventory was 8,000. Sheep and lamb farms reported 32,000 head of animals. Dairy cow numbers totaled to 13,000 animals. The USDA also reported there were 1.86 million head of chickens in 2005 in West Virginia, which excluded broilers. The total inventory value summed to $9.8 million. Broilers accounted for another 88.5 million animals and a value of $163.3 million. There were 2.4 million turkeys raised in 2005. The combined value from poultry in WV during 2005 was $222.7 million.

All hay harvested in the state during 2005 totaled 575,000 acres with an average yield of 1.86 tons/acre, which resulted in a total of 1.070 million tons per year (Figure 2.4). This crop was valued at $65.5 million. Alfalfa hay area harvested totaled 35,000 acres across the state with an average yield of 2.8 tons per acre. The value of the harvest was $10.1 million for alfalfa and alfalfa mixtures. Area planted to corn for all purposes in 2005 totaled 45,000 acres, from which 28,000 acres were harvested for grain (Figure 2.4). The production averaged 109.0 bushels per acre and the value of production totaled $6.1 million. There were 16,000 acres reportedly planted in corn for silage purposes. Yields averaged 15.5 tons per acre and silage production was estimated at 248,000 tons. Soybeans were planted on 18,000 acres and harvested acreage for beans was 17,000 acres (Figure 2.4). The value of production was $3.2 million. Wheat was planted on 7,000 acres in 2005. Area harvested for grain totaled 5,000 acres. The average yield was 60 bushels per acre and the value of production was $915,000. Of the total 645,400 acres of
farmland for crops, 616 acres were suitable for switchgrass and short rotation woody crop, respectively (BFIN 1999).

According to a report by Walsh et al. (1999), 1.3 million tons of primary forest residues with a delivered price of less than $50 per dry ton were produced annually, among which 0.73 million tons were with delivered cost less than $30 per dry ton, 0.33 million tons were with delivered cost at $30-40 per dry ton, and 0.3 million tons were with delivered cost at $40-50 per dry ton (Table 2.1). There were 0.14 million dry tons of primary mill residues were delivered at less than $20 per dry ton, 0.32 million dry tons were delivered at the unit price of $20-30, and 0.51 million dry tons were delivered at the unit price of $30-50.

The delivered costs for all the agricultural residues and perennial woody crops were $30 per dry ton or higher (Table 2.1). About 0.01 million dry tons of agricultural residues were delivered at the unit price of $30-40 and 0.04 million dry tons were delivered at the unit price of $40-50. The delivered cost of corn was less than $50/dry ton in West Virginia. Among the perennial woody crops produced in West Virginia, 23% were delivered at the unit price of $30-40 and 77% of them were delivered at the unit price of $40-50.

Table 2.1 Estimated annual biomass quantities (dry tons) by delivered price in West Virginia.

<table>
<thead>
<tr>
<th>Biomass resource</th>
<th>&lt;$20/dry ton delivered</th>
<th>$20-30/dry ton delivered</th>
<th>$30-40/dry ton delivered</th>
<th>$40-50/dry ton delivered</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary forest residues</td>
<td>727,000</td>
<td>329,000</td>
<td>296,500</td>
<td></td>
<td>1,352,500</td>
</tr>
<tr>
<td>Primary mill residues</td>
<td>136,000</td>
<td>323,000</td>
<td>508,000</td>
<td></td>
<td>967,000</td>
</tr>
<tr>
<td>Urban wood residue</td>
<td>105,236</td>
<td>70,157</td>
<td>0</td>
<td>0</td>
<td>175,393</td>
</tr>
<tr>
<td>Agricultural residues¹</td>
<td>0</td>
<td>0</td>
<td>12,008 (0%)</td>
<td>39,387 (77%)</td>
<td>51,395</td>
</tr>
<tr>
<td>Perennial woody crops</td>
<td>0</td>
<td>0</td>
<td>269,250</td>
<td>921,049</td>
<td>1,190,299</td>
</tr>
</tbody>
</table>

¹Value in parenthesis indicates percentage of residues from corn.
(Source: Walsh et al. 1999)

2.2 Wood Residues
(2.41 potential million dry tons, 72.7% of the total biomass)

Wood residues could be classified into three categories of primary, secondary, and tertiary residue (Figure 2.5). Primary wood residues include logging residues, fuel treatment, and tree trimming. Mill residues and pulping liquors are classified as secondary forest residue, and urban wood residues/wastes are tertiary residues. West Virginia produces 2.41 million dry tons of wood residues per year. Of wood residues in West Virginia, there are 1.34 million dry tons of logging residues left in the woods annually, which accounts for 55% of the total wood residues (Figure 2.6). The annually production of mill residue is 941,868 dry tons and accounts
for 39% of the total. Other wood residues produced annually in West Virginia include 118,590 dry tons of biomass of urban tree residues across the state and 12,716 dry tons of pallet residues.

Figure 2.5 Composition of wood residues.

Figure 2.6 Wood residues (dry tons) in West Virginia.

2.2.1 Logging Residue
(1.34 potential million dry tons, 40.4% of the total biomass)

West Virginia had more than 1000 licensed timber operators in 2005 (Figure 2.7). The average harvest tract size was 96 acres and most and many of the larger harvests were located in southern West Virginia (Milauskas and Wang 2006) (Figure 2.8). The annual harvest averaged 264,000 acres changing from 273,185 acres in 1996 to 237,281 acres in 2005 (WVDODF 2006)
The general trend of annual harvest decreased slightly over the year. However, it increased 8.6 and 9.3% from the year of 1996 to 1997 and 2001 to 2003, respectively. The annual harvest has remained stable with about 250,000 acres since 2000.

Figure 2.7 Licensed loggers in West Virginia by district as of 03/24/06. (Source: WVDOF 2006)

Figure 2.8 Annual harvest acres by county.
Line intersect sampling was implemented in 1995 and 2002 surveys to estimate the quantity of logging residues in West Virginia (Grushecky et al. 1997, 2005, 2006). To calculate volumes and weights of logging residues, the equations first developed by Warren and Olsen (1964) and modified by Van Wagner (1968) was used. Van Wagner (1968, 1982) outlined the development of logging residue equations in detail. The following equation was used to estimate residue weights in southern West Virginia (Van Wagner 1968):

\[
W = \frac{11.65S\Sigma d^2}{L}
\]

Where, \(W\) = weight of logging residue in green tons/acre; \(S\) = specific gravity of the logging residue; \(d\) = diameter of logging residue at intersection with transects; and \(L\) = length of the sampling transect.

The 1995 survey of logging residues in West Virginia (Grushecky et al. 1997) revealed that the average volume of residue left on the ground after harvest in West Virginia was 504.4 ft\(^3\)/acre or 8.4 tons/acre in weight with average volume in any one piece of residue of 12.9 ft\(^3\) statewide. The survey also showed that of the six West Virginia Division of Forestry districts, District 4 had the greatest overall volume (900 ft\(^3\)/acre) and weight (15 tons/acre) estimates of logging residue following harvesting. Pulpwood (at least 8 feet in length and 4 inches in diameter) and sawlog (at least 11 inches in diameter and 8 feet in length) size residues were most commonly found in the area, which accounted for 86 and 13 percent of total logging residues, respectively. Among species groups, red oak, mixed hardwood, yellow-poplar, and soft-hardwood were commonly occurred.
More recently, another survey of logging residues was conducted in a 14-county region of southern West Virginia (Grushecky et al. 2006). Harvested areas were at least 20 acres in size to eliminate any edge bias. Each harvested site was selected randomly from a list of all harvests conducted during 2000-2001 in the study region. Harvest sites were located using West Virginia Division of Forestry logging notification forms. Notification of timber harvesting in West Virginia is mandated under the 1992 Logging Sediment Control Act (WVDOF 2005). The total volume left on the harvested sites was estimated to be 623.7 ft$^3$/acre in the region with average overall weight of 10.4 tons/acre (Table 2.2), which was 24 percent higher than the total logging residues produced in the entire state of West Virginia in 1995. Considering the average annual harvest of 250,000 acres, it yields a total of 2,600,000 tons of available logging residues per year in West Virginia. The minimum tonnage found among the 70 harvest sites visited was 2.3 tons/acre and the maximum was 20.3 tons/acre. Boone County had the highest average with 12.7 tons/acre left after harvest followed by Wyoming, Cabell, and Raleigh counties with 12.0, 11.7, and 11.7 tons/acre, respectively (Table 2.2).

<table>
<thead>
<tr>
<th>County</th>
<th>Number of sites</th>
<th>Average weight (tons/acre)</th>
<th>SD</th>
<th>CV</th>
<th>Maximum (tons/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boone</td>
<td>5</td>
<td>12.7</td>
<td>4.2</td>
<td>33.1</td>
<td>16.4</td>
</tr>
<tr>
<td>Wyoming</td>
<td>5</td>
<td>12.0</td>
<td>5.1</td>
<td>42.3</td>
<td>19.8</td>
</tr>
<tr>
<td>Cabell</td>
<td>5</td>
<td>11.7</td>
<td>6.0</td>
<td>51.6</td>
<td>19.8</td>
</tr>
<tr>
<td>Raleigh</td>
<td>5</td>
<td>11.7</td>
<td>3.7</td>
<td>31.7</td>
<td>15.9</td>
</tr>
<tr>
<td>Kanawha</td>
<td>5</td>
<td>11.3</td>
<td>3.6</td>
<td>32.3</td>
<td>15.1</td>
</tr>
<tr>
<td>Fayette</td>
<td>5</td>
<td>11.1</td>
<td>5.6</td>
<td>50.4</td>
<td>20.3</td>
</tr>
<tr>
<td>Clay</td>
<td>5</td>
<td>11.0</td>
<td>3.4</td>
<td>31.2</td>
<td>15.0</td>
</tr>
<tr>
<td>McDowell</td>
<td>5</td>
<td>10.8</td>
<td>2.4</td>
<td>22.5</td>
<td>13.2</td>
</tr>
<tr>
<td>Wayne</td>
<td>5</td>
<td>10.5</td>
<td>2.3</td>
<td>21.7</td>
<td>13.8</td>
</tr>
<tr>
<td>Mingo</td>
<td>5</td>
<td>10.1</td>
<td>2.4</td>
<td>23.6</td>
<td>13.6</td>
</tr>
<tr>
<td>Lincoln</td>
<td>5</td>
<td>9.0</td>
<td>2.9</td>
<td>32.9</td>
<td>12.8</td>
</tr>
<tr>
<td>Nicholas</td>
<td>5</td>
<td>8.2</td>
<td>5.0</td>
<td>61.4</td>
<td>17.0</td>
</tr>
<tr>
<td>Mercer</td>
<td>5</td>
<td>7.8</td>
<td>3.7</td>
<td>47.6</td>
<td>12.9</td>
</tr>
<tr>
<td>Logan</td>
<td>5</td>
<td>7.1</td>
<td>2.8</td>
<td>40.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Overall</td>
<td>70</td>
<td>10.4</td>
<td>4.0</td>
<td>38.2</td>
<td>20.3</td>
</tr>
</tbody>
</table>

(Source: Grushecky et al. 2006)

Oak was the most prevalent species group by weight and volume, averaging 5.0 tons/acre (281.1 ft$^3$/acre) over the study area (Table 2.3). Miscellaneous hardwoods, yellow-poplar, and maple species followed the oaks with 2.7, 1.2, and 1.2 tons/acre, respectively. The maximum amount of residue left on a sampled harvest of any one species group was 15.1 tons/acre for oaks.

Large-end diameters were greatest in oak species (9.6 in.), followed by miscellaneous hardwoods (9.4 in.) and yellow-poplar (9.1 in.). Overall lengths were similar by species (Table 2.4). A total of 810,584 tons of available residue were present per year during the study period in the 14-county region (Table 2.5). Kanawha County had the highest available residue with an average of 13,712 acres harvested and 130,264 tons of available residues per year. These calculations were also performed for logging residue that met current species and length...
specifications for the engineered wood products in West Virginia (Table 2.6). Results indicate that approximately 332,649 tons of residue met engineered wood products specifications in West Virginia.

Table 2.3 Logging residues by species group in southern West Virginia.

<table>
<thead>
<tr>
<th>Species group</th>
<th>Average weight (tons/acre)</th>
<th>Maximum weight (tons/acre)</th>
<th>Average volume (ft³/acre)</th>
<th>Maximum volume (ft³/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak</td>
<td>5.0 (3.1)</td>
<td>15.1</td>
<td>281.1 (171.5)</td>
<td>59.9</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2.7 (2.0)</td>
<td>8.8</td>
<td>158.8 (118.0)</td>
<td>525.4</td>
</tr>
<tr>
<td>Maple</td>
<td>1.2 (1.0)</td>
<td>3.5</td>
<td>75.1 (59.3)</td>
<td>213.6</td>
</tr>
<tr>
<td>Yellow-poplar</td>
<td>1.2 (1.0)</td>
<td>4.7</td>
<td>95.5 (80.6)</td>
<td>376.6</td>
</tr>
<tr>
<td>Softwoods</td>
<td>0.1 (0.3)</td>
<td>1.9</td>
<td>8.8 (24.3)</td>
<td>156.4</td>
</tr>
<tr>
<td>Cherry</td>
<td>0.1 (0.2)</td>
<td>0.9</td>
<td>4.4 (11.2)</td>
<td>59.9</td>
</tr>
</tbody>
</table>

(Source: Grushecky et al. 2006)

Table 2.4 Logging residue piece size by species group.

<table>
<thead>
<tr>
<th>Species group</th>
<th>Total number</th>
<th>Large diameter (inches)</th>
<th>Small-end diameter (inches)</th>
<th>Length (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oaks</td>
<td>566</td>
<td>9.6 (3.9)</td>
<td>4.8 (2.0)</td>
<td>20.1 (10.6)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>300</td>
<td>9.4 (4.6)</td>
<td>5.0 (2.4)</td>
<td>21.2 (12.0)</td>
</tr>
<tr>
<td>hardwood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow-poplar</td>
<td>244</td>
<td>9.1 (3.0)</td>
<td>5.2 (2.0)</td>
<td>20.3 (12.1)</td>
</tr>
<tr>
<td>Softwoods</td>
<td>25</td>
<td>9.0 (3.8)</td>
<td>4.8 (1.5)</td>
<td>21.2 (14.0)</td>
</tr>
<tr>
<td>Cherry</td>
<td>20</td>
<td>8.1 (3.1)</td>
<td>5.3 (2.4)</td>
<td>19.1 (11.9)</td>
</tr>
<tr>
<td>Maple</td>
<td>131</td>
<td>7.8 (2.8)</td>
<td>4.5 (1.4)</td>
<td>20.0 (11.8)</td>
</tr>
</tbody>
</table>

* Average size characteristics are ranked by small-end diameter and are presented along with their respective SD (in parentheses).

(Source: Grushecky et al. 2006)

Based on the average annual logging residue production of 10.4 tons/acre and the 2005 statewide harvesting data by county (WVDOF 2006), the logging residue left on the harvest sites could be estimated by county in West Virginia (Figure 2.10). The annual production estimation of logging residues ranged from 2,620 in Jefferson County to 178,973 greens tons in Boone County with an average of 51,565 tons.
Table 2.5 Total residue weight (tons/acre) found remaining after harvest by county.

<table>
<thead>
<tr>
<th>County</th>
<th>Total weights</th>
<th>Percentage of length specification</th>
<th>Total available acres</th>
<th>Acres harvested</th>
<th>Total tons/year</th>
<th>Total mill days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boone</td>
<td>12.7</td>
<td>0.87</td>
<td>11.0</td>
<td>9,342</td>
<td>102,762</td>
<td>51</td>
</tr>
<tr>
<td>Cabell</td>
<td>11.7</td>
<td>0.75</td>
<td>8.8</td>
<td>1,965</td>
<td>17,292</td>
<td>9</td>
</tr>
<tr>
<td>Clay</td>
<td>11</td>
<td>0.9</td>
<td>9.9</td>
<td>6,447</td>
<td>63,825</td>
<td>32</td>
</tr>
<tr>
<td>Fayette</td>
<td>11</td>
<td>0.79</td>
<td>8.7</td>
<td>9,169</td>
<td>79,770</td>
<td>40</td>
</tr>
<tr>
<td>Kanawha</td>
<td>11.3</td>
<td>0.84</td>
<td>9.5</td>
<td>13,712</td>
<td>130,264</td>
<td>65</td>
</tr>
<tr>
<td>Lincoln</td>
<td>9</td>
<td>0.71</td>
<td>6.4</td>
<td>3,220</td>
<td>20,608</td>
<td>10</td>
</tr>
<tr>
<td>Logan</td>
<td>7.1</td>
<td>0.7</td>
<td>5.0</td>
<td>6,860</td>
<td>34,300</td>
<td>17</td>
</tr>
<tr>
<td>McDowell</td>
<td>10.8</td>
<td>0.89</td>
<td>9.6</td>
<td>9,223</td>
<td>88,541</td>
<td>44</td>
</tr>
<tr>
<td>Mercer</td>
<td>7.8</td>
<td>0.83</td>
<td>6.5</td>
<td>2,606</td>
<td>16,939</td>
<td>8</td>
</tr>
<tr>
<td>Mingo</td>
<td>10.1</td>
<td>0.88</td>
<td>8.9</td>
<td>4,101</td>
<td>36,499</td>
<td>18</td>
</tr>
<tr>
<td>Nicholas</td>
<td>8.2</td>
<td>0.53</td>
<td>4.3</td>
<td>9,363</td>
<td>40,261</td>
<td>20</td>
</tr>
<tr>
<td>Raleigh</td>
<td>11.7</td>
<td>0.83</td>
<td>9.7</td>
<td>9,755</td>
<td>94,624</td>
<td>47</td>
</tr>
<tr>
<td>Wayne</td>
<td>10.5</td>
<td>0.78</td>
<td>8.2</td>
<td>2,057</td>
<td>16,867</td>
<td>8</td>
</tr>
<tr>
<td>Wyoming</td>
<td>12</td>
<td>0.82</td>
<td>9.8</td>
<td>6,942</td>
<td>68,032</td>
<td>34</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
<td>94,762</td>
<td>810,584</td>
<td>405</td>
</tr>
</tbody>
</table>

(Source: Grushecky et al. 2006)

Table 2.6 Residue weights by species used in engineered wood products in West Virginia.

<table>
<thead>
<tr>
<th>County</th>
<th>Total weights</th>
<th>Percentage of length specification</th>
<th>Total available acres</th>
<th>Acres harvested</th>
<th>Total tons/year</th>
<th>Total mill days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boone</td>
<td>6.4</td>
<td>0.83</td>
<td>5.3</td>
<td>9,342</td>
<td>49,513</td>
<td>25</td>
</tr>
<tr>
<td>Cabell</td>
<td>3.9</td>
<td>0.72</td>
<td>2.8</td>
<td>1,965</td>
<td>5,502</td>
<td>3</td>
</tr>
<tr>
<td>Clay</td>
<td>5.1</td>
<td>0.85</td>
<td>4.3</td>
<td>6,447</td>
<td>27,722</td>
<td>14</td>
</tr>
<tr>
<td>Fayette</td>
<td>5.3</td>
<td>0.79</td>
<td>4.2</td>
<td>9,169</td>
<td>38,510</td>
<td>19</td>
</tr>
<tr>
<td>Kanawha</td>
<td>4.7</td>
<td>0.81</td>
<td>3.8</td>
<td>13,712</td>
<td>52,106</td>
<td>26</td>
</tr>
<tr>
<td>Lincoln</td>
<td>2.9</td>
<td>0.81</td>
<td>2.3</td>
<td>3,220</td>
<td>7,406</td>
<td>4</td>
</tr>
<tr>
<td>Logan</td>
<td>4.2</td>
<td>0.72</td>
<td>3.0</td>
<td>6,860</td>
<td>20,580</td>
<td>10</td>
</tr>
<tr>
<td>McDowell</td>
<td>3.4</td>
<td>0.85</td>
<td>2.9</td>
<td>9,223</td>
<td>26,747</td>
<td>13</td>
</tr>
<tr>
<td>Mercer</td>
<td>2.8</td>
<td>0.78</td>
<td>2.2</td>
<td>2,606</td>
<td>5,733</td>
<td>3</td>
</tr>
<tr>
<td>Mingo</td>
<td>5.6</td>
<td>0.91</td>
<td>5.1</td>
<td>4,101</td>
<td>20,915</td>
<td>10</td>
</tr>
<tr>
<td>Nicholas</td>
<td>4.1</td>
<td>0.57</td>
<td>2.3</td>
<td>9,363</td>
<td>21,535</td>
<td>11</td>
</tr>
<tr>
<td>Raleigh</td>
<td>4.6</td>
<td>0.78</td>
<td>3.6</td>
<td>9,755</td>
<td>35,118</td>
<td>18</td>
</tr>
<tr>
<td>Wayne</td>
<td>2.8</td>
<td>0.67</td>
<td>1.9</td>
<td>2,057</td>
<td>3,908</td>
<td>2</td>
</tr>
<tr>
<td>Wyoming</td>
<td>3.8</td>
<td>0.67</td>
<td>2.5</td>
<td>6,942</td>
<td>17,355</td>
<td>9</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
<td>94,762</td>
<td>332,649</td>
<td>166</td>
</tr>
</tbody>
</table>

(Source: Grushecky et al. 2006)

If we averaged the logging residue production rates (8.4 and 10.4 tons per acre) of two previous surveys in West Virginia and multiplied by the annual harvest of 250,000 acres, the annual production of logging residues would be estimated at 2.35 million green tons. If using a
moisture content of 43% (wet basis) for logging residues (Koch 1985, Bowyer et al. 2003), the state of West Virginia could produce 1.34 million dry tons of logging residue biomass.

![Figure 2.10 Estimation of logging residue production by county.](image)

### 2.2.2 Mill Residues
(941,868 potential dry tons, 28.4% of the total biomass)

West Virginia’s forest products industry produces a substantial amount of mill residues from its manufacturing activities in all six forest districts (Figure 2.11). Chips, sawdust, and bark are the major wood residues, which account for 97% of the total (Figure 2.12).

According to a survey conducted by the WVU Extension Service in 1984 and 1985, over one half of the green weight of the sawlogs entered larger sawmills in West Virginia became residues in the forms of chips, sawdust, and bark with weekly production of 11,337, 5,798, and 5,712 tons, respectively (Patterson and Zinn 1990). Total mill residue production increased to 27,223 tons per week in 1986, among which 95.4% was sawmill residues and only 4.6% was from secondary processing facilities. Due to either difficulties in finding markets for wood residues or long trucking distance, producers gave away or dumped 5,408 tons of residue per week, which accounted for 20% of the total produced (Patterson and Zinn 1990). Of the total wood residues produced weekly, 18,798 tons or 69% was sold to the major markets and 1,379 tons or 5% was consumed through local markets.
In this study, the mill residue estimation was based on the mail surveys done by the Appalachian Hardwood Center (AHC) at West Virginia University. The AHC has conducted the annual survey of mill residues consistently over the past 6 years. This process includes an initial
mailing sent to all producers and consumers and a follow-up mailing to non-respondents. Survey information includes plant type, plant location, types/amount/species of residues generated, and types/amount/species of residues demanded.

The AHC surveys reported that the total wood residue production increased 10% to 30,064 tons per week from 1986 to 1999 as expansion of the wood industries occurred in West Virginia during the late 1990's. Weekly mill residue production in 2002 declined by 7,283 tons or 24.2% compared to the production of 30,600 tons per week in 2000 (Hutchinson 1999, 2000, Bragonje et al. 2005) (Figure 2.13). Weekly production continued to drop in 2003 to 21,302 tons, which was 8,949 tons or 29.6% less than the production in 2000. Since 2004, mill residue production has steadily increased from 27,652 tons in 2004 to 40,161 tons per week in 2005. Mill residue production by product type over the last six years was summarized in Table 2.7. West Virginia Division of Forestry District 3 produces the greatest amount of mill residues per year (Figure 2.14). The total weekly production in the state was 10,975, 16,814, and 11,388 tons for bark, sawdust, and chips, respectively in 2005 (Figure 2.15) (Bragonje et al. 2005).

Mill residue production averaged 28,733 tons per week ranging from 21,302 to 40,161 tons per week during 1999 and 2005 (Figure 2.13). Eighty-two percent of mill residues were produced in primary processing industry and while the other 18% were produced in secondary processing industry. If a moisture content of 42% (Koch 1985, Bowyer et al. 2003) was used for mill residues from primary industry, the annual production of mill residue averaged 941,868 dry tons.

![Figure 2.13 Annual mill residue supply and demand in green tons in West Virginia.](image)

---

For the next question, please read the document carefully and provide your response.
Figure 2.14 Weekly production of bark, chip, and sawdust between 1999 – 2005.

Figure 2.15 Total bark, chip, and sawdust available by county in West Virginia. (Source: Bragonje et al. 2005)
Table 2.7 Mill residue production in green tons from 1999 to 2005.

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
<th>2000</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tons/week</td>
<td>%</td>
<td>tons/week</td>
<td>%</td>
<td>tons/week</td>
<td>%</td>
</tr>
<tr>
<td>Sawdust</td>
<td>10382</td>
<td>34.5</td>
<td>11754</td>
<td>39.2</td>
<td>7559</td>
<td>30.8</td>
</tr>
<tr>
<td>Bark</td>
<td>7767</td>
<td>25.8</td>
<td>7336</td>
<td>24.5</td>
<td>7553</td>
<td>30.8</td>
</tr>
<tr>
<td>Chips</td>
<td>11355</td>
<td>37.8</td>
<td>10153</td>
<td>33.9</td>
<td>7960</td>
<td>32.5</td>
</tr>
<tr>
<td>Planer shavings</td>
<td>50</td>
<td>0.2</td>
<td>51</td>
<td>0.2</td>
<td>123</td>
<td>0.5</td>
</tr>
<tr>
<td>Slabs/Edgings/End trim</td>
<td>510</td>
<td>1.7</td>
<td>657</td>
<td>2.2</td>
<td>507</td>
<td>2.1</td>
</tr>
<tr>
<td>Others</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>827</td>
<td>3.3</td>
</tr>
</tbody>
</table>

2.2.3 Urban Tree Residues
(118,590 potential dry tons, 3.6% of the total biomass)

Several national and regional studies of urban wood waste materials included urban tree residue (UTR) in larger classifications of municipal solid waste wood (McKeever and Skog 2003, Wiltsee 1998), but the statistics were not specific to UTR or West Virginia. One available nationwide survey of UTR has been published which included West Virginia in regional estimates (Table 2.8) (NEOS 1994).

Table 2.8 Estimates of urban tree residue production in West Virginia 1994.

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of generators</th>
<th>Regional means1 (dry tons/year)</th>
<th>Total possible (dry tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial tree care firms</td>
<td>42</td>
<td>2,089</td>
<td>87,738</td>
</tr>
<tr>
<td>Utility line maintenance</td>
<td>8</td>
<td>10,484</td>
<td>83,872</td>
</tr>
<tr>
<td>Municipal tree divisions</td>
<td>22</td>
<td>3,107</td>
<td>68,354</td>
</tr>
<tr>
<td>Total residue</td>
<td></td>
<td></td>
<td>239,964</td>
</tr>
</tbody>
</table>

(Source: NEOS 1994 - published in cubic yards/year, converted to dry tons/year)

1 The regional means are based on estimates from the thirteen states in the Southeastern Regional Biomass Energy Program (SERBEP). Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia.

Applying the regional means from such a large area may not accurately reflect the amount of residues produced for the same types of generators in West Virginia. The state is characterized by a small population and a large geographic range with few metropolitan areas. Only two that would be classified as “small urban” areas of 50,000 to 99,000 residents (Charleston and Huntington), but none that would rank as “medium urban” (100,000 to 499,999) or “large urban” (500,000 or more residents) as defined in the NEOS study. Difficult hilly terrain is another feature of West Virginia that could affect the rate at which UTR is generated compared to other states included in the study. West Virginia is the third most heavily forested state in the U.S., with forests covering 78 percent of the land area (USDA 200b, Griffith and Widmann 2003). This is an important factor particularly when considering utility line maintenance and clearing activities.

(1) Commercial tree services

Wiltsee (1998) proposed a method to estimate the amount of urban tree residue (UTR) generated by commercial tree services within any metropolitan area. After talking to tree service companies and developing estimates based on the volume and average number of truckloads they fill per day or week, he concluded that nationwide, on average, one tree service crew generates about 1000 tons/year of green wood waste (~ 570 dry tons/year/crew). He also determined that the vast majority of tree service companies are small firms that operate with one crew, and that most cities have a small number of larger firms that operate with two to six crews. For any selected area of interest he counted the number of tree service companies in the phone book, added 20 percent to that number to estimate the number of crews operating in the area, and multiplied that number by 1000 tons/year. This method allows some refinement to reflect local crew numbers and practices.
In order to evaluate the potential for application of Wiltsee’s method to West Virginia tree service companies, a mail and phone survey was conducted. Approximately 63 tree trimming & removal service companies were found listed in various industry directories. Companies that were primarily “landscaping” services were not included in the survey because they were not full time tree trimming and removal services, and the residues they generate also include grass clippings and fall leaf collection which are not of interest in this study.

Of the original 63 tree service companies in West Virginia, 13 were determined to be out of business. The exact status of several others remains undetermined. For example, several did not mention a company name on their phone answering machine message, and did not return phone calls describing the survey, but they were left in the reported total of 50. Most of the commercial tree services are small companies with one or sometimes two crews. Some are only part time operations. Most are concentrated around the larger populations centers in the state (Figure 2.16). Many counties have no commercial tree service companies.

For each responding tree service, residue weights were estimated based on truck capacity, approximate number of truckloads of residues generated per week (Wiltsee 1998), rather than on actual weights. Companies reported approximately 25 percent solids (usually greater than 12-inch diameter) and 75 percent in the form of chips, which compares favorably with the percentages reported for the Southeastern U.S. (Figure 2.17). Weights were computed using 1000 dry pounds/yd³ for solids based a conservative average dry weight of 37 pounds/ft³ for solid oak, maple and yellow-poplar wood (Panshin and de Zeeuw 1980), and 460 dry pounds/yd³ for chips “blown in from chipper” computed from 30 pounds/ft³ green (Koch 1985).

In our study, the residue estimation from commercial tree service was based on the production rate of 570 dry tons per year per full time crew (Wiltsee 1998) and 50 full time tree service crews, which yielded a total of 28,500 dry tons. Although it is only 27% of the regional mean by NEOS (1994), it yields a reasonable estimate of total tonnage generated by West Virginia tree removal and trimming companies.

Figure 2.16 West Virginia tree service companies by county.
In addition to the survey, one “typical” tree service company was visited which employed one full time tree trimming and removal crew of three people, with occasional part time employees when needed. Equipment included a “bucket” truck, and a disk type chipper capable of processing 12 inch diameter logs. The company performed some landscaping services with an additional crew, and the landscaping service did allow for the utilization of any residue generated by the tree service crew that could not be disposed of by other means. Most residues were removed from job site, but firewood size solid material was often left behind at the request of the property owner or neighbor. Most of the residues were chipped, as much as possible up to 12-inch diameter limit of the chipper in order to make transport and disposal easier (Figure 2.18a). This company had little or no difficulty giving away chipped or solid material.
Figure 2.18 Sample chips generated.
(a) by a typical commercial tree care service; (b) by utility line maintenance activity.

(2) Utility line maintenance

Asplundh is the primary utility line maintenance company currently operating in West Virginia, and 95% of their activity in the state is utility line maintenance. The two other major firms associated with utility line maintenance were contacted but Davey had sold off that part of their business to concentrate on tree care, and Bartlett had no contracts for utility line maintenance in West Virginia at the time the survey was undertaken.

Basic details about Asplundh’s operations were obtained from phone conversations with individuals at two regional offices; Frostburg MD which manages activities in 2/3 of the state, and Roanoke VA which manages activities in the southern 1/3 of the state. Detailed information was obtained from direct observations of several different crews in the field and discussions with crew members and their supervisors.

Asplundh has many more tree trimming & removal crews operating within the state than all the private tree service companies combined (~ 325 crews) but their activities are very different from the private services. There are about 175 bucket and manual trimming crews operating in the northern 2/3 of the state, and 150 crews (100 bucket crews and 50 manual) for southern 1/3 of the state.

Two very different functions are performed; maintenance of existing rights of way, and clearing of new rights of way. In general, existing rights of way in urban areas are revisited every 3 years, and rural areas are revisited every 4 years. Crews are involved mostly in trimming limbs, and any trees that have died since the last visit. Most of the residue is in the form of limbs and foliage. The process of clearing new rights of way, which includes providing utility access to new residential and commercial construction, has the potential to generate much more residue, and more of that residue can be in the form of whole trees, than would occur during the course of routine maintenance activities.

A distinction is also made between “maintained” areas and “non-maintained” areas. All residues generated must be removed from maintained areas such as city streets, parks, residences, and businesses, if the property owner desires removal. However, crews are permitted to leave all residues on sites that are generated along non-maintained areas. Regardless of the area, as much material as possible is left on site with as little processing as possible.
Bucket truck crews usually consist of two crew members, with a drum type chipper. Chippers are capable of processing material up to 3 or 4 inch diameter (compared to up to 12 inch diameter for many commercial tree services) which reflects the need to leave most material on site and to process as little material as necessary. Bucket crews are mostly involved in trimming limbs along existing utility lines with relatively easy vehicle access.

Manual crews, with two to three members, operate very differently from the bucket crews. They work on existing rights of way with difficult access, sometimes reachable only with all terrain vehicles or on foot. They also work on clearing new rights of way. They are equipped only with a smaller truck and tree climbing equipment. They generally work on sites that require no residue removal, but when necessary will team up with a bucket crew for that purpose.

Percentages of wood residue types generated by utility line maintenance firms were estimated for the southeastern United States (NEOS 1994) (Figure 2.19). Chipped residue generated varies in consistency among different types of crews (Figure 2.18b). Operational differences between commercial tree services and utility line maintenance, (chipper type and capacity, size of material chipped) can be seen from a comparison of the chips (Figure 2.18). There is generally a larger percentage of wood chips in the material from commercial tree services, and a larger percentage of twigs and foliage in the material from utility line maintenance.

![Pie chart](image)

**Figure 2.19 Wood residue types generated by utility line maintenance firms for the southeastern United States.**
(Source: NEOS 1994)

The operations of three bucket truck crews were observed. From the discussions with crew members and their foremen, 2 truckloads of chips per week were generally considered to be average. Three manual crews were observed as well. One was operating on foot in extremely
inaccessible areas so the amount of residue generated was very limited. Two other manual crews operating on different sites were observed clearing utility access from existing lines to new home construction. Both sites required tree trimming and tree felling, and provided an opportunity to estimate the amount of residue generated. Estimates were based on actual measurements, observations, and discussions with personnel involved in that activity (Table 2.9).

Table 2.9 Residue generated by utility line maintenance and clearing in West Virginia.

<table>
<thead>
<tr>
<th>Crew type</th>
<th>Number of crews</th>
<th>Total residue (dry tons/yr/crew)</th>
<th>Total dry tons per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucket crew</td>
<td>200</td>
<td>125</td>
<td>25,000</td>
</tr>
<tr>
<td>Manual crew</td>
<td>125</td>
<td>500</td>
<td>62,500</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>87,500</td>
</tr>
</tbody>
</table>

(3) Municipal tree trimming and removal divisions

The survey of municipal tree trimming and removal activities consisted entirely of phone conversations with city personnel, city managers, engineers, public works department employees were responsible for tree care and tree removal in a given community. City crews remove only dead and diseased trees, and only from city property. Tree removal from private property is almost always the responsibility of the property owner who has to hire a commercial tree trimming/removal service. No definite pattern was detected in how communities deal with UTR. Each has its own combination of demand for service, space restrictions, equipment limitations, and fiscal constraints. Few West Virginia communities have full time tree trimming and removal employees. Tree trimming and removal activity ranges from 5% to 100% of a public works crew’s time. Some communities contract the work out to private firms.

Percentages of wood residue types generated by municipal tree care activities were estimated in the Southeastern US (Figure 2.20). In West Virginia, much of the larger material is given away for firewood. In towns that have a chipper, chips are given away, used in city parks, composted, or sent to a landfill. Occasionally high quality logs are sold to local sawmills but those events were rare. The most useful statistics available came from those communities that sent UTR to the local landfill. Using those data, the amount of UTR was estimated for towns within several population ranges and the total annual production was 2,590 dry tons (Table 2.10).

Table 2.10 Urban tree residue generated by West Virginia municipalities.

<table>
<thead>
<tr>
<th>Population range</th>
<th>Number of municipalities</th>
<th>Yield per range (dry tons/year)</th>
<th>Total residue (dry tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10,000</td>
<td></td>
<td>negligible</td>
<td></td>
</tr>
<tr>
<td>10,000 to 30,000</td>
<td>12</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>30,000 to 50,000</td>
<td>2</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>More than 50,000</td>
<td>2</td>
<td>1250</td>
<td>2,500</td>
</tr>
<tr>
<td>Total residue</td>
<td></td>
<td></td>
<td>2,590</td>
</tr>
</tbody>
</table>
Figure 2.20 Wood residue types generated by municipal tree divisions for the southeastern United States.
(Source: NEOS 1994)

(4) Summary
The total estimated production of urban tree residue was 118,590 dry tons per year in West Virginia by the three generators surveyed (Figure 2.21), including 28,500 dry tons per year from commercial tree service, 87,500 tons from utility line maintenance, and 2,590 dry tons per year of municipal tree trimming and removal.

Figure 2.21 Estimated total urban tree residues by generator in West Virginia.
2.2.4 Pallet Residue
(12,716 potential dry tons, 0.3% of the total biomass)

(1) Pallet Manufacture and Recycling in the U.S.
There are approximately 2 billion pallets in use in the United States at any given time, and they are an established and critical part of the United States commercial economy. The wood pallet and container manufacturing industry has faced two main challenges in the years since 2000. One is increasing competition from substitute materials, and the second is competition for hardwood raw material.

Wood pallets are not the only option for shippers. Plastic and corrugated cardboard pallets are also commonly available. Wood remains the preferred pallet material because it is 20% of the cost of a plastic pallet, and is more durable than cardboard (IBISWorld 2006). In closed loop shipping systems where the pallet is returned to the shipper or never actually leaves the possession of the owner, plastic is becoming more common because its durability outweighs the initial cost.

Wood still makes up more than 90% of the domestic pallet market (IBISWorld 2006). Seventy percent of wood pallets are made from hardwood, the other 30 percent from softwood, but increasing competition for the hardwood resource has come from other users of low grade material such as for railroad ties, paper pulp, and hardwood flooring. Raw materials costs are the largest single expense for wood pallet manufacturers, accounting for from 50 to 60% of the cost of manufacturing and delivering a new wood pallet (IBISWorld 2006). It is also a very labor intensive industry, so wages are the next highest expense, but account for only around 25% of the cost. (IBISWorld 2006)

Pallet manufacturing is highly competitive, and markets are primarily driven by price. Therefore, manufacturers are forced to keep prices low in whatever way they can. One way to meet customer demand is to provide used or recycled pallets. Recent production practices within the industry reflect the importance that pallet recycling has achieved within the marketplace. By the year 2000, more than half of 3031 U.S. manufacturers and recyclers in the industry were involved in recycling either as part of their production or as their total production (Figure 2.22).

Pallet recycling increased constantly through the 1990s to meet the need for lower prices. In 1999, the industry produced 429 million new pallets, and recovered 299 million. Nearly 218 million pallets were returned to service either through repair or recycling (Bejune 2001). In 2004, 500 million new wood pallets were manufactured and 300 million were reconditioned in the US. (Polar Inertia 2005).

Since 2000, total production of new wood pallets has remained relatively unchanged due to competition for the hardwood lumber resource leading to a combination of limited availability and higher prices for new lumber. Meanwhile there has been a steady increase in the number of used and reconditioned pallets available to meet the demand for pallets.

In recent years though, general market reports in Pallet Enterprise magazine (Brindley 2004, 2006), an industry trade journal, have consistently stated that the demand for recycled pallets is increasing, but the demand for recyclable pallet cores exceeds the available supply. This has been the situation for almost three years, and is likely to continue as long as demand for wood pallets continues at or near current levels.
Manufacture new pallets only, 44%

Manufacture new and recover used pallets, 47%

Recover used pallets only, 9%

Figure 2.22 The U.S. wood pallet and container industry in 2000. (Source: White 2004)

(2) West Virginia Pallet Industry

In 1997, West Virginia companies accounted for just over 1% of the total US production of wood pallets and containers (US Census Bureau 1997). There is no information available on the number of pallets actually in use in the state. Review of several industry directories determined that there are currently approximately 23 firms operating in West Virginia that list wood pallets and containers as their primary or secondary products (Figure 2.23). The heaviest concentrations are near the major industrial areas of the state, in Wood County, in and around Parkersburg, and Wayne County, in and around Huntington.

Several companies provide pallet management services to their own customers (retrieval, repair, return, and inventory). Additional pallet recycling companies operate nearby in adjacent states and do retrieve pallets from within West Virginia. At least one national pallet management company provides service through an affiliated location in West Virginia, and several other management companies operating in adjacent states could expand into West Virginia. Many of the large national manufacturers and retailers that do business in West Virginia are part of national pallet management programs, thus avoiding accumulations of unwanted pallets at their locations in the state.

There will always be orphan pallets, but industry pressures suggest their numbers will decline. Indicators on the national level suggest that used wood pallets are more valuable as used pallets or parts. An active recycling sector in the state industry contributes to reduce the number of orphan pallets. Other pallet end users that are near pallet removal or recycling companies will have no difficulty eliminating any accumulation of used pallets in desirable sizes.

Those West Virginia companies that contract for third party management services will not accumulate used or orphan pallets in any great quantity. The companies that provide those services minimize the potential for any major accumulation of used pallets. There are parts of the state where the distance to the nearest recycler is too far to make retrieval of used pallets economically viable, but those areas are also away from the highest concentrations of
manufacturing and economic activity. The number of orphan pallets in those areas should remain small.

We surveyed wood pallet manufacturing and recycling companies in West Virginia. Of the 15 companies that responded to the survey, ten manufacture only new pallets, four process only used pallets, and one company processes both new and used pallets. Ten manufacturers of new pallets that responded to the survey combine to produce over 2,700,000 pallets per year. However, it is important to note that less than 274,000 of those, approximately 13%, are delivered to customers within West Virginia. The other 87% are delivered to surrounding states. During the survey of West Virginia landfills it was found that very few wood pallets were being landfilled in the state. As much as 90% of recovered material can go back into the manufacture pallets. Damaged pallets that cannot be repaired and unusable components are commonly turned into wood chips for use as fuel, landscape mulch, animal bedding, compost, soil amendment, or core material for particle board.

Three small pallet recycling companies retrieved a combined total of 220,000 pallets per year, primarily from within West Virginia. All three stated that they could sell more if they could obtain more pallet cores. The medium-size pallet recycling company retrieved 300,000 used pallets, while the large company retrieved 3 million pallets per year, primarily from outside West Virginia. Data from these companies showed approximately 83% recovery and reuse of pallets and lumber components from their retrieved pallets. This is only slightly lower than the 87% reported nationwide (Bejune 2001). Applying an 83% recovery rate, and assuming an average pallet weight of 50 pounds and moisture content of 15% (Koch 1985), the total biomass generated by the five responding pallet recycling companies is approximately 12,716 dry tons, all of which is currently sold as mulch.

Figure 2.23 Wood pallet and container manufacturers and recyclers in West Virginia.
2.3 Agriculture Residues
(903,826 potential dry tons, 27.3% of the total biomass)

Similarly, agriculture residues can also be classified into three categories; primary, secondary, and tertiary residues (Figure 2.24). Primary agriculture residues include crop residues, grains used for ethanol, biodiesel, and bioproducts, perennial grasses, and perennial woody crops. Secondary agriculture residue consists of animal manures and food/feed processing residues, while tertiary agriculture residue refers to municipal solid waste (MSW), post-consumer residues and agriculture waste that reaches landfills. West Virginia produces 903,826 dry tons of agriculture residue per year, including 101,000 dry tons of grass seed residue, 10,618 dry tons of corn stover, 131,440 dry tons of corn silage, 1,585 dry tons of soybean residue, 3,731 dry tons of all wheat straw, 3,838 potential dry tons of switchgrass, 2,593 potential dry tons of short rotation woody crop, 662,780 dry tons of animal manure, and 26,241 dry tons of solid wood material from the construction and demolition waste citation (Figure 2.25). Animal manure is the primary source of agriculture residues produced in West Virginia and accounted for 70% of the total (Figure 2.25). It was followed by corn related residues (16%).

Figure 2.24 Composition of agriculture residues.
Figure 2.25 Agriculture residues in dry tons in West Virginia.  
(Source: USDA/NASS 2006)

2.3.1 Grass Seed Straw  
(101,000 potential dry tons, 3.0% of the total biomass)

Harvested acres, yield, and production of alfalfa hay for the years of 1996-2005 for each county in West Virginia were derived by using the 2005 West Virginia Agricultural Statistics report (USDA/NASS 2006).  Alfalfa hay area harvested ranged from 35,000 to 55,000 acres with an average of 47,000 acres during 1996 and 2005 in West Virginia (Figure 2.26, Table 2.11) (USDA/NASS 2006).  In 2005, the yield was 2.8 tons per acre and production totaled 98,000 tons.  Alfalfa and alfalfa mixtures can be grouped with grass seed straw residue (Frear et al. 2005).  The residue production of alfalfa and alfalfa mixtures was determined by using a simple calculation of average harvested acres (47,000) multiplied by average yield (tons per acre) (2.68) during 1996 and 2005.  If moisture content of 20% for grass seed residue was used, the residue biomass production averaged 101,000 dry tons per year ranging from 78,400 to 132,000 dry tons per year in West Virginia (Figure 2.27).  The BTU range for hay is 6000-6500 BTU/lb (http://www.egrass.com/green_energy/green_questions.htm).
Figure 2.26 Production of alfalfa and alfalfa mixtures in West Virginia in 2005. (Source: USDA/NASS 2006)

Table 2.11 Production of alfalfa and alfalfa mixtures by year in West Virginia.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvested acres (1000 acres)</th>
<th>Yield (tons/acre)</th>
<th>Production (1000 tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>40</td>
<td>2.80</td>
<td>112</td>
</tr>
<tr>
<td>1997</td>
<td>55</td>
<td>3.00</td>
<td>165</td>
</tr>
<tr>
<td>1998</td>
<td>50</td>
<td>3.00</td>
<td>150</td>
</tr>
<tr>
<td>1999</td>
<td>50</td>
<td>2.10</td>
<td>105</td>
</tr>
<tr>
<td>2000</td>
<td>50</td>
<td>3.20</td>
<td>160</td>
</tr>
<tr>
<td>2001</td>
<td>50</td>
<td>2.50</td>
<td>125</td>
</tr>
<tr>
<td>2002</td>
<td>50</td>
<td>2.50</td>
<td>125</td>
</tr>
<tr>
<td>2003</td>
<td>45</td>
<td>2.50</td>
<td>113</td>
</tr>
<tr>
<td>2004</td>
<td>45</td>
<td>2.40</td>
<td>108</td>
</tr>
<tr>
<td>2005</td>
<td>35</td>
<td>2.80</td>
<td>98</td>
</tr>
</tbody>
</table>

(Source: USDA/NASS 2006)
2.3.2 Corn
(142,058 potential dry tons, 4.3% of the total biomass)

Corn stover residue was derived by averaging annual production of corn for the years 1996 to 2005 (Figure 2.28, Table 2.12), and then using a conversion equation from corn to straw (tons/year of collectible corn stover = annual production (tons) x residue factor (1.1) x available factor (0.25)) to get total straw production (Klass 1998, Frear et al. 2005). The production of corn in tons was converted from bushels based on conversion factors for bushel to cubic foot (0.8036:1) and bulk density of ear corn (56.0 pounds per cubic foot) (SMICO 2004). A moisture content of 47% for corn stover was used to determine the final biomass in dry tons (Klass 1998). The annual corn stover production averaged 10,617.7 dry tons during the last ten years in the state (Table 2.12.) Corn stover has a BTU rating of 6,300 per pound.

Table 2.12 Production of corn for grain and corn stover in West Virginia, 1996-2005.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvested acres (1000 acres)</th>
<th>Yield per acre (bushels)</th>
<th>Corn production (1000 bushels)</th>
<th>Corn stover production (dry tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>40</td>
<td>105.0</td>
<td>4,200</td>
<td>13,773.9</td>
</tr>
<tr>
<td>1997</td>
<td>36</td>
<td>95.0</td>
<td>3,400</td>
<td>11,150.3</td>
</tr>
<tr>
<td>1998</td>
<td>34</td>
<td>80.0</td>
<td>2,700</td>
<td>8,854.6</td>
</tr>
<tr>
<td>1999</td>
<td>20</td>
<td>65.0</td>
<td>1,300</td>
<td>4,263.3</td>
</tr>
<tr>
<td>2000</td>
<td>35</td>
<td>130.0</td>
<td>4,550</td>
<td>14,921.7</td>
</tr>
<tr>
<td>2001</td>
<td>26</td>
<td>120.0</td>
<td>3,120</td>
<td>10,232.0</td>
</tr>
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<td>2002</td>
<td>30</td>
<td>105.0</td>
<td>3,150</td>
<td>10,330.4</td>
</tr>
<tr>
<td>2003</td>
<td>27</td>
<td>115.0</td>
<td>3,105</td>
<td>10,182.8</td>
</tr>
<tr>
<td>2004</td>
<td>29</td>
<td>131.0</td>
<td>3,799</td>
<td>12,458.8</td>
</tr>
<tr>
<td>2005</td>
<td>28</td>
<td>109.0</td>
<td>3,052</td>
<td>10,009.0</td>
</tr>
</tbody>
</table>

(Source: USDA/NASS 2006)
Figure 2.28 Corn production of West Virginia in 2005. (Source: USDA/NASS 2006)

West Virginia also harvested on average 22,100 acres of corn for silage per year with an average yield of 15.4 green tons per acre during 1996 and 2005 (USDA/NASS 2006) (Figure 2.28, Table 2.13). Similarly, if a moisture content of 47% was used, the dry biomass production from corn silage changed from 169,600 tons in 1996, to 207,230 tons in 2001, and to 131,440 tons in 2005 with an average production 174,105 tons per year (Figure 2.29).

Table 2.13 Production of corn silage by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvested acres (1000 acres)</th>
<th>Yield (tons/acre)</th>
<th>Production (1000 green tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>20</td>
<td>16</td>
<td>320</td>
</tr>
<tr>
<td>1997</td>
<td>28</td>
<td>14</td>
<td>392</td>
</tr>
<tr>
<td>1998</td>
<td>24</td>
<td>15</td>
<td>360</td>
</tr>
<tr>
<td>1999</td>
<td>35</td>
<td>8.5</td>
<td>298</td>
</tr>
<tr>
<td>2000</td>
<td>19</td>
<td>19</td>
<td>361</td>
</tr>
<tr>
<td>2001</td>
<td>23</td>
<td>17</td>
<td>391</td>
</tr>
<tr>
<td>2002</td>
<td>19</td>
<td>16.5</td>
<td>314</td>
</tr>
<tr>
<td>2003</td>
<td>19</td>
<td>15.5</td>
<td>295</td>
</tr>
<tr>
<td>2004</td>
<td>18</td>
<td>17</td>
<td>306</td>
</tr>
<tr>
<td>2005</td>
<td>16</td>
<td>15.5</td>
<td>248</td>
</tr>
</tbody>
</table>

(Source: USDA/NASS 2006)
2.3.3 Soybean Residue
(1,585 potential dry tons, 0.1% of the total biomass)

On average, soybeans are planted on 16,400 acres annually in West Virginia since 2000 (Figure 2.30). This has produced a yield of 41.3 bushels per acre on average and the annual production of soybeans averaged 674,000 bushels (Table 2.14). A similar method was used to convert soybean production to soybean residue biomass as we did for corn (Frear et al. 2005). The production of soybeans in tons was converted from bushels based on conversion factors for bushel to cubic foot (0.8036:1) and bulk density of soybeans (38.0 pounds per cubic foot) (http://www.fao.org/docrep/S4314E/s4314e0q.htm). A moisture content of 44% for soybean residue was used to determine the final biomass in dry tons. The annual soybean residue biomass production averaged 1,585 dry tons ranging from 1,446 to 1,947 dry tons during the last six years in the state (Figure 2.31). Soybeans have been found to have a 6300 BTU/lb (Baldwin 2005).

Table 2.14 Production of soybeans for grain by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvested acres (1000 acres)</th>
<th>Yield (bushels/acre)</th>
<th>Production (1000 bushels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>15</td>
<td>47</td>
<td>705</td>
</tr>
<tr>
<td>2001</td>
<td>16</td>
<td>42</td>
<td>672</td>
</tr>
<tr>
<td>2002</td>
<td>17</td>
<td>37</td>
<td>629</td>
</tr>
<tr>
<td>2003</td>
<td>15</td>
<td>41</td>
<td>615</td>
</tr>
<tr>
<td>2004</td>
<td>18</td>
<td>46</td>
<td>828</td>
</tr>
<tr>
<td>2005</td>
<td>17</td>
<td>35</td>
<td>595</td>
</tr>
</tbody>
</table>

(Source: USDA/NASS 2006)
Figure 2.30 Soybean production in West Virginia in 2005. (Source: USDA/NASS 2006)

Figure 2.31 Production of soybean residue biomass.
2.3.4 All Wheat
(3,731 potential dry tons, 0.1% of the total biomass)

Harvested acres, yield, and production of all wheat were obtained from the 2006 West Virginia Agricultural Statistics (USDA/NASS 2006). The average harvested acreage was 7,400 acres with an average yield of 53.3 bushels per acre during 1996 and 2005, which resulted in a total annual production of 403,200 bushels for all wheat (Table 2.15). Wheat straw biomass was determined by using the equation: wheat straw = yield (tons/yr) x residue factor (2.5) x available factor (0.25) (Klass 1998, Frear et al. 2005). Other conversion factors used include: bushels to cubic foot ratio (0.8036:1), bulk density of wheat seed (40.5 pounds per cubic foot), and moisture content of 9%. The annual production of wheat straw biomass generally decreased from 4,581 dry tons in 1996 to 2,777 dry tons in 2005 with an average of 3,731 dry tons per year (Figure 2.32). Wheat straw has a Btu value of 7680 Btu/lb when dry and at 20% moisture content 5908 Btu/lb rating (www.se.gov.sk.ca/green/PDF/pub6.pdf).

Table 2.15 Production of wheat by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvested acres (1000 acres)</th>
<th>Yield (bushels/acre)</th>
<th>Production (1000 bushels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>11</td>
<td>45</td>
<td>495</td>
</tr>
<tr>
<td>1997</td>
<td>9</td>
<td>54</td>
<td>486</td>
</tr>
<tr>
<td>1998</td>
<td>8</td>
<td>57</td>
<td>456</td>
</tr>
<tr>
<td>1999</td>
<td>7</td>
<td>57</td>
<td>399</td>
</tr>
<tr>
<td>2000</td>
<td>9</td>
<td>61</td>
<td>549</td>
</tr>
<tr>
<td>2001</td>
<td>8</td>
<td>58</td>
<td>464</td>
</tr>
<tr>
<td>2002</td>
<td>7</td>
<td>48</td>
<td>336</td>
</tr>
<tr>
<td>2003</td>
<td>7</td>
<td>41</td>
<td>287</td>
</tr>
<tr>
<td>2004</td>
<td>5</td>
<td>52</td>
<td>260</td>
</tr>
<tr>
<td>2005</td>
<td>5</td>
<td>60</td>
<td>300</td>
</tr>
</tbody>
</table>

(Source: USDA/NASS 2006)
2.3.5 Switchgrass and Perennial Woody Crops
(6,791 potential dry tons, 0.2% of the total biomass)

Switchgrass (*Panicum virgatum*, L., Poaceae), a high yielding warm-season perennial grass, has been identified as a good source for bioenergy production due to its excellent conservation attributes and good compatibility with conventional farming practices (McLaughlin 1992, McLaughlin et al. 1999). Switchgrass is an important component of the native, highly productive North American Tallgrass Prairie (Weaver 1968, Risser et al. 1981, and McLaughlin et al. 1999).

Switchgrass cultivars were evaluated in Iowa on 18 sites with a total of 9 yields (Moser and Vogel 1995). These tests included two harvests, single cut late in the growing season and 2-cut system with the first cut typically at the date of formation of seed heads, around July. Yield performance was compared between the two harvests. Yield performance comparisons showed that the best bioenergy cultivar for the Northeast are “Kanlow” or “Cave-in-Rock”. The 2-cut system generally produced the highest yields, but this is dependent upon precipitation levels. The average yields found in their study were 7 dry tons/acre. A vital consideration is the maintenance required by a deep rooting system. The timing in which the cuttings are carried out is crucial to yield. Additionally, the later harvests of switchgrass have generally lower ash contents (Sanderson and Wolf 1995). Reduction of ash content of the feedstock makes it more acceptable for use for combustion endpoints where boiler slagging of high ash fuels can be a problem (Miles et al. 1993, McLaughlin et al. 1996).

The prediction of switchgrass production potential in West Virginia was based on the Oak Ridge Integrated Bioenergy Analysis System (ORIBAS) from the Bioenergy Feedstock Information Network (BFIN 1999). The ORIBAS predicted facility numbers and locations that could be supported in a state using available cropland data and feedstock demand. The ORIBAS algorithm also located a facility individually, which minimized the marginal delivered price for feedstock until all the available land in the state had been processed. A total of 616 acres of cropland was suitable for switchgrass or short rotation woody crops in West Virginia by ORIBAS (BFIN 1999). The average annual yield of switchgrass was 6.23 tons per acre with an average farmgate price of $32.57 per ton (Table 2.16). Total perennial woody crops in West Virginia were estimated at 4.21 dry tons per acre per year with 22.6% delivered at $30-40/dry ton and 77.4% delivered at the unit price of $40-50 (Table 2.16). The annual potential production of switchgrass and short rotation woody crops would be 3,838 dry tons and 2,593 dry tons, respectively.

Table 2.16 Switchgrass and short rotation woody crop in West Virginia.

<table>
<thead>
<tr>
<th></th>
<th>Average yield (ton/acre/yr)</th>
<th>Farmgate price ($/ton)</th>
<th>Acreage of suitable cropland</th>
<th>Acreage of land with farmgate price</th>
<th>Average cash rent ($/acre/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>6.23</td>
<td>$32.57</td>
<td>616</td>
<td>522, 551, 577</td>
<td>-</td>
</tr>
<tr>
<td>Woody crop</td>
<td>4.21</td>
<td>$54.31</td>
<td>616</td>
<td>0, 0, 0</td>
<td>53</td>
</tr>
</tbody>
</table>

(Source: BFIN 1999)
2.3.6 Animal Manure

(622,780 potential dry tons, 18.8% of the total biomass)

The largest potential source of biomass from food/feed processing and post consumer wastes is animal manure. Dried animal manure is worth only about $20/ton, but the value rises to $80/ton if the manure is converted to various chemicals currently produced from petroleum (USDA 2002b). In terms of energy production, one cow’s average daily manure translates into enough energy to burn a 100-watt bulb for a day (USDA 2002b). High concentrations of animal waste usually cause environmental concerns, such as waste runoff and air pollution. Animal manure can be readily collected from confined animal feeding operations (CAFOs), which have increased slightly for cattle and hogs while increased considerably for poultry (ORNL 2005). The amount of animal waster produced in the U.S. is staggering. The daily production of wastes from chickens is essentially equal to the amount to feed used. This means for every truckload of feed that is brought onto the farm, a similar load of waste is removed. A million hen complex, for example, produces 125 tons of wet manure a day (Bell 1990). Typical dairy farm, beef feedlot operations, and swine operations produce approximately 80 lb, 51 lb, and 63 lb of waste per day per 1,000 pounds of livestock live weight, respectively (USDA 2002a). The daily waste production is estimated at 61 lb, 46 lb, 80 lb, and 44 lb per 1,000 pounds of livestock live weight for layer, pullet, broiler, and turkey, respectively (USDA 2002a).

Current manure management practices on the Nation’s animal feeding operations are being evaluated in light of the changing structure of the livestock industry and the quantity, location, and sources of manure nutrients (Gollehon et al. 2001). Using data collected for the census of agriculture by the National Agricultural Statistics Service, the number of confined animals and the amount of manure nutrients can be estimated. Confined animals include animals such as feedlot beef, dairy cows, swine, poultry, and other cattle that sufficient amounts of manure would accumulate requiring removal on a regular basis. Animals not confined include range cattle and animals of all types produced on small farms (Gollehon et al. 2001). Gollehon et al. (2001) estimated nation-wide manure nutrient production on farms with confined livestock operations. They then used the reported on-farm production of major field crops and pastureland to determine the possible nutrient assimilative capacity. The final step was to determine the balance between production and nutrient need for each crop uptake and the pastureland applications on the farm level.

An assessment of dairy manure production in Washington in 2005 was determined using an average production per county (Frear et al. 2005). Values were adjusted based on animal type (milker or calves). An 85% collection factor was used for the entire state based on medium and large confined animal operations. Cattle manure values were obtained in a similar fashion. County averages were determined and two animal types were used (cattle and calves). Then simple multiplication factors were applied to determine manure production. Similar methods were used to determine manure production for several animal types.

A mail survey was used to survey 375 poultry producers in five counties of West Virginia (Basden et al. 1994). The analysis of their survey included frequency distributions for each questionnaire item and tables for the responses to the 52 questions including litter production and uses. A 90% confidence interval was used for all questions. They showed that 10% of poultry farmers produce 0-100 tons of litter per year, 53% or the majority of them produce 101 to 400 tons, 13% produce 401 to 600 tons, 13% produce 601 to 800 tons, and 10% produce over 800 tons of litter per year (Figure 2.33) (Basden et al. 1994).
To calculate manure production, a measurement of animal unit (AU) of 1,000 pounds of live animal weight was used. Using the average animal weights from census data, estimates at the farm level could be made. Operations of different sizes were examined to assess changes in industry structure and impacts of regulations based on production. Schmidt and Pinapati (1999) obtained data from the National Agricultural Statistical Services (USDA 1999) to produce statistics for animal waste, which was based simply on animal numbers at farm locations.

The animal manure production rate per day per AU for the state of West Virginia is summarized in Table 2.17. The number of farms in the state of West Virginia decreased steadily from 1982 to 1997 (USDA 2001) (Figure 2.34a and Figure 2.35a). It declined 36% from 22,651 to 14,524, while farms for confined animals reduced 43% from 1,836 to 1038. The total number of animal units reduced slightly from 1982 to 1987 and then increased 12% for all animals and 27% for confined animals from 1987 to 1997 (Figure 2.34b and Figure 2.35b). A similar trend was found for manure production for all animals (Figure 2.34c). The annual production of animal manure for all animals including feedlot beef, other cattle, poultry, swine, and dairy cows varied from 567,027 dry tons in 1987 to 675,263 dry tons in 1997 with an average of 622,780 dry tons per year in West Virginia (Figure 2.34c). However, the manure production of confined animals increased steadily from 1982 to 1997 with an increase of 49% (Figure 2.35c).

The number of farms with confined animals in West Virginia decreased 46%, 52%, 16%, 68%, and 56% for feedlot beef, other cattle, poultry, swine, and dairy cows, respectively between 1982 and 1997 (Table 2.18). During the same time period, the number of animal units for confined animals decreased 38%, 41%, 33%, and 41% for feedlot beef, other cattle, swine, and diary cows, respectively. However, the number of animal units for confined poultry has more than doubled from 1982 to 1997. Similarly, manure production of confined animals declined for feedlot beef, other cattle, swine, and dairy cows and almost tripled for the confined poultry.
In this study, we derived the animal manure production (622,780 dry tons per year) in West Virginia by averaging the manure production of all animals (608,229 dry tons in 1982, 567,027 dry tons in 1987, 640,599 dry tons in 1992, and 675,263 dry tons in 1997) (Figure 2.34c, Table 2.18).

Table 2.17 Animal manure production in West Virginia.

<table>
<thead>
<tr>
<th></th>
<th>Dairy cow</th>
<th>Feedlot beef</th>
<th>Swine</th>
<th>Poultry</th>
<th>Poultry</th>
<th>Poultry</th>
<th>Poultry</th>
<th>Sheep</th>
<th>Horse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Layer</td>
<td>Pullter</td>
<td>Broiler</td>
<td>Turkey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (lb/day/AU)</td>
<td>82</td>
<td>58</td>
<td>52</td>
<td>61</td>
<td>46</td>
<td>80</td>
<td>44</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Volume (ft³/day/AU)</td>
<td>1.3</td>
<td>0.93</td>
<td>0.83</td>
<td>0.93</td>
<td>0.73</td>
<td>1.26</td>
<td>0.69</td>
<td>0.96</td>
<td>0.63</td>
</tr>
</tbody>
</table>

1An animal unit (AU) represents 1,000 pounds of live animal weight.
(Source: USDA 2000a)
Figure 2.34 Animal and manure production in West Virginia for all animals. 
(a) total number of farms, (b) total number of animal units, (c) manure in dry tons. 
(Source: USDA 2001)
Figure 2.35 Animal and manure production in West Virginia for confined animals. (a) total number of farms, (b) total number of animal units, (c) manure in dry tons. (Source: USDA 2001)
Table 2.18 Animal and manure nutrients in West Virginia.

<table>
<thead>
<tr>
<th>Category</th>
<th>All animals (both confined and not confined)</th>
<th>Confined animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Farms</td>
<td>Total number of animal units</td>
</tr>
<tr>
<td>Feedlot beef</td>
<td>1,650</td>
<td>7,104</td>
</tr>
<tr>
<td>Other cattle</td>
<td>13,814</td>
<td>308,427</td>
</tr>
<tr>
<td>Poultry</td>
<td>2,737</td>
<td>29,839</td>
</tr>
<tr>
<td>Swine</td>
<td>1,755</td>
<td>4,282</td>
</tr>
<tr>
<td>Diary cows</td>
<td>2,695</td>
<td>46,677</td>
</tr>
<tr>
<td>Feedlot beef</td>
<td>1,177</td>
<td>5,933</td>
</tr>
<tr>
<td>Other cattle</td>
<td>11,894</td>
<td>284,536</td>
</tr>
<tr>
<td>Poultry</td>
<td>1,687</td>
<td>35,483</td>
</tr>
<tr>
<td>Swine</td>
<td>1,114</td>
<td>4,225</td>
</tr>
<tr>
<td>Diary cows</td>
<td>1,454</td>
<td>36,318</td>
</tr>
<tr>
<td>Feedlot beef</td>
<td>1,004</td>
<td>4,363</td>
</tr>
<tr>
<td>Other cattle</td>
<td>11,627</td>
<td>306,086</td>
</tr>
<tr>
<td>Poultry</td>
<td>1,157</td>
<td>56,302</td>
</tr>
<tr>
<td>Swine</td>
<td>742</td>
<td>3,498</td>
</tr>
<tr>
<td>Diary cows</td>
<td>910</td>
<td>31,480</td>
</tr>
<tr>
<td>Feedlot beef</td>
<td>826</td>
<td>4,089</td>
</tr>
<tr>
<td>Other cattle</td>
<td>11,396</td>
<td>313,180</td>
</tr>
<tr>
<td>Poultry</td>
<td>1,100</td>
<td>67,232</td>
</tr>
<tr>
<td>Swine</td>
<td>556</td>
<td>2,132</td>
</tr>
<tr>
<td>Diary cows</td>
<td>646</td>
<td>24,954</td>
</tr>
</tbody>
</table>

(Source: USDA 2001)
2.3.7 Construction and Demolition Wastes
(26,241 potential dry tons, 0.8% of the total biomass)

Contact was made with persons in the West Virginia Solid Waste Management Board (SWMD) for collecting the municipal solid wastes (MSWs) data. This is the state agency that oversees the operation of the eighteen licensed landfills in West Virginia. Each landfill reports monthly, to the SWMB, the tonnage of waste received. This waste is broken out into several categories and after discussion with SWMB personnel it was concluded that the only category with significant amounts of solid wood is the Construction and Demolition (C&D) waste category. This is corroborated by a study funded by the WV SWMB to obtain waste characterization data for the State of West Virginia’s waste stream. The methodology for conducting this study was a source specific approach in which individual components of the waste stream were sampled, sorted, and weighed (GAI Consultants 1997) (http://www.wv.gov/Offsite.aspx?u=http://www.state.wv.us/swmb).

The WV SWMB supplied supervisory contacts at each landfill in West Virginia. These individuals were contacted so that estimates on the percentage of solid wood waste from construction and demolition (C&D) sources reaching landfills could be obtained. Calls were made to all eighteen landfill managers with ten being willing to answer some basic questions about the amount of solid wood going into the respective facilities. All ten agreed that aside from the C&D category the amount of solid wood going into landfills was limited.

Figure 2.36 Municipal waste landfills in West Virginia.
(Source: WVSWMB 2003)
When asked to estimate the percentage of solid wood material contained in the C&D material, the ten responses varied considerably, ranging from 5% to 40%. For the sake of discussion, the estimations of tons of solid wood waste potentially recoverable from the actual tonnage of C&D waste material was presented in high and low values based upon the aforementioned estimations of solid wood material contained in the C&D waste. The following sections described in tabular and graphic form each of the five wastesheds in West Virginia and presented the estimations of potentially recoverable solid wood material from each of the eighteen licensed landfills (Figure 2.36).

The SWMB has delineated the state into seven zones, referred to as “Wastesheds” for management purposes. The most recent complete waste stream analysis was done by the SWMB in 2003 (Table 2.19). Specifics from each wasteshed and its respective landfill(s) are as follows (Table 2.20):

Table 2.19 Licensed landfills in West Virginia.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Town</th>
<th>County</th>
<th>Permit Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brooke County Sanitary Landfill</td>
<td>Colliers</td>
<td>Brooke</td>
<td>SWF-1013/WV0108029</td>
</tr>
<tr>
<td>Charleston Landfill</td>
<td>Charleston</td>
<td>Kanawha</td>
<td>SWF-1004/WV010970</td>
</tr>
<tr>
<td>Disposal Services</td>
<td>Hurricane</td>
<td>Putnam</td>
<td>SWF-1026/WV01090000</td>
</tr>
<tr>
<td>Elkins-Randolph County Landfill</td>
<td>Elkins</td>
<td>Randolph</td>
<td>SWF-206/WV0109525</td>
</tr>
<tr>
<td>Greenbrier County Landfill</td>
<td>Lewisburg</td>
<td>Greenbrier</td>
<td>SWF-2068-94/WV01009425</td>
</tr>
<tr>
<td>H.A.M. Sanitary Landfill Inc.</td>
<td>Peterstown</td>
<td>Monroe</td>
<td>SWF-2032/WV0109240</td>
</tr>
<tr>
<td>Meadowfill Landfill</td>
<td>Bridgeport</td>
<td>Harrison</td>
<td>SWF-1032/WV0109193</td>
</tr>
<tr>
<td>Mercer County Sanitary Landfill</td>
<td>Princeton</td>
<td>Mercer</td>
<td>SWF-7190/WV0109258</td>
</tr>
<tr>
<td>Nicholas County Landfill</td>
<td>Craigsville</td>
<td>Nicholas</td>
<td>SWF-2072/WV01099444</td>
</tr>
<tr>
<td>Northwestern Disposal</td>
<td>Parkersburg</td>
<td>Wood</td>
<td>SWF-1025/WV0109410</td>
</tr>
<tr>
<td>Pocahontas County Landfill</td>
<td>Marlinton</td>
<td>Pocahontas</td>
<td>SWF-200/WV0109436</td>
</tr>
<tr>
<td>Raleigh County Landfill</td>
<td>Lanark</td>
<td>Raleigh</td>
<td>SWF-8163/WV0109118</td>
</tr>
<tr>
<td>S &amp; S, Inc.</td>
<td>Clarksburg</td>
<td>Harrison</td>
<td>SWF-4902/WV0109151</td>
</tr>
<tr>
<td>Short Creek Landfill (North Fork)</td>
<td>Wheeling</td>
<td>Ohio</td>
<td>SWF-1034/WV0109517</td>
</tr>
<tr>
<td>Sycamore Landfill, Inc.</td>
<td>Hurricane</td>
<td>Putnam</td>
<td>SWF-5808/WV019215</td>
</tr>
<tr>
<td>Tucker County Solid Waste Authority</td>
<td>Davis</td>
<td>Tucker</td>
<td>SWF-8295/WV0109126</td>
</tr>
<tr>
<td>Wetzel County Landfill</td>
<td>New Martinsville</td>
<td>Wetzel</td>
<td>SWF-1021/WV0109185</td>
</tr>
<tr>
<td>L C S Services, Inc.</td>
<td>Hedgesville</td>
<td>Berkeley</td>
<td>SWF-1020/WV0109476</td>
</tr>
</tbody>
</table>

(Source: WVSWMB 2003)
Table 2.20 Waste stream composition for six wastesheds in 2003.

<table>
<thead>
<tr>
<th>Wastesheds (%)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>E</th>
<th>F</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal solid waste (MSW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential waste</td>
<td>42.9</td>
<td>42.9</td>
<td>42.9</td>
<td>33.8</td>
<td>37.4</td>
<td>34.2</td>
</tr>
<tr>
<td>Commercial waste</td>
<td>16.2</td>
<td>21.8</td>
<td>21.8</td>
<td>40.9</td>
<td>48.0</td>
<td>48.4</td>
</tr>
<tr>
<td>Sewage Sludge¹</td>
<td>15.7</td>
<td>2.9</td>
<td>2.9</td>
<td>2.3</td>
<td>2.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Non municipal solid waste (NMSW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asbestos</td>
<td>0.0</td>
<td>4.8</td>
<td>4.8</td>
<td>0.0</td>
<td>4.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Construction/demolition</td>
<td>5.6</td>
<td>9.3</td>
<td>9.3</td>
<td>19.6</td>
<td>4.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Industrial sludges</td>
<td>3.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Industrial waste</td>
<td>14.5</td>
<td>11.2</td>
<td>11.2</td>
<td>2.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other waste²</td>
<td>1.8</td>
<td>1.7</td>
<td>1.7</td>
<td>0.5</td>
<td>2.9</td>
<td>5.7</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0.0</td>
<td>2.9</td>
<td>2.9</td>
<td>0.0</td>
<td>0.0</td>
<td>5.9</td>
</tr>
<tr>
<td>Contaminated soil</td>
<td>0.0</td>
<td>2.5</td>
<td>2.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

¹According to 33CSR1, Solid Waste Management Rule, “Municipal Solid Waste means any house-hold or commercial solid waste as defined in this rule and any sludge from a waste treatment plant or a water treatment plant.”

²Other waste consists of various components that on an individual basis make up less than 2% of the wastestream.

(Source: WVSWMB 2003)

Prior to 2003, reports to the SWMB were not separated into the various subsets described in Tables 2.19 and 2.20. Therefore, the following estimations of solid wood material in C&D waste were for the years 2003-2004. The yearly high/low tonnage estimates were summarized for each licensed WV landfill (Figures 2.37, 2.38, 2.39). Based on the actual tonnages of C&D waste accepted into the respective landfills, the total estimated amount (5% of total=low, 40% of total=high) of tonnage of solid wood theoretically recoverable was presented for the aforementioned years (Table 2.21). If averaging both low and high estimates between 2003 and 2005, the average annual production would be 32,801 green tons in West Virginia. If the wood material was assumed to have moisture content of 20% (McCloy et al. 1999) the total annual production of C&D wood biomass would average 26,241 dry tons.

Table 2.21 Estimation of potential solid wood material from C&D waste in West Virginia.

<table>
<thead>
<tr>
<th>Year</th>
<th>Low estimate (green tons)</th>
<th>High estimate (green tons)</th>
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<tr>
<td>2003</td>
<td>7025</td>
<td>56200</td>
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<tr>
<td>2004</td>
<td>7119</td>
<td>56956</td>
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<td>2005</td>
<td>7723</td>
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Figure 2.37 Solid wood tonnage high/low estimation in 2003.

Figure 2.38 Solid wood tonnage high/low estimation in 2004.
Figure 2.39 Solid wood tonnage high/low estimation in 2005.
3. BIOMASS USE INVENTORY

3.1 Logging Residues

Although significant quantities of logging residues remain after harvest in West Virginia, lack of markets and the cost of recovery limit the utilization of these residues (Johnson and Lee 1988). There are no statistical data that indicate the amount of logging residues being used annually in the state. A small portion of logging residues is likely used for firewood or other purposes in West Virginia. However, there is growing interest in more efficient utilization of logging residues and conversion of these underutilized materials to bioproducts or bioenergy need to be emphasized.

3.2 Mill Residues

3.2.1 Mill Residue Uses

Although mill residue production in West Virginia is substantial, there is opportunity for increased utilization of these residues. If we consider all the demands of mill residues were utilized, the utilization rate was 99% in 1999 (Figure 3.1). It remained about 15% between 2000 and 2004. The utilization rate went up to 68% in 2005. In 1999, the weekly demand of mill residues was 29,885 tons, which was close to the supply of 30,064 tons per week (Figure 2.13). Among those demands, 62.8% of consumers required for sawdust, 31.8% of them were for chips, and 6.2% were for barks. The relatively high demand in 1999 contributed to a request of 12,000 tons of sawdust for pellet fuel by a hardwood pellets company, which accounted for 40.2% of the total mill residue demand in that year. The demand dropped significantly in 2000 with a weekly demand of 5,645 tons, which was 81.1% lower than the weekly demand in 1999. The demand for mill residue continued to drop in 2002 and remained relatively consistent from 2002 to 2004. However, a huge rebound of demand for mill residue occurred in 2005 with weekly demand of 27,501 tons, which was almost eight times of the demand in 2004.

Chips, sawdust, and bark are primary residues produced by the forest product industry in West Virginia, they account for more than 97% of the total wood residue production. Among the six forest districts in West Virginia, District 3 consistently produced large amount of chips, sawdust, and bark between 1999 and 2005, which accounted for 46% of the total production of mill residues in the state (Figure 2.14). More than 90% of the demands were made in four forest districts 1, 3, 5, and 6 with weekly demand of 10,900, 16,351, 16,145, and 25,810 tons, respectively (Figure 3.2).
Figure 3.1 Utilization rates of mill residues in West Virginia.

Figure 3.2 Weekly demands of bark, chip, and sawdust between 1999 and 2005. (*Indicates 10 times of the number displayed)
The use of mill residues has changed over the years in West Virginia. Boiler fuel was the primary use of mill residues (65.7%) in 1999 and then decreased gradually to 33.6% in 2002, and to 17.5% in 2005 (Figure 3.3). Mill residues for mulch averaged 15.5% each year. Mill residues for pellet fuel have steadily increased.

Specifically in 2005, pellet fuel was the major use of mill residues and accounted for 66.7% of the total. It was followed by boiler fuel (17.5%) and mulch (8.6%). Approximately 7.2% of mill residues were used for composite materials in 2005 (Figure 3.4).
According to the West Virginia Timber Product Output (TPO) assessment completed by the USDA Forest Service (Hansen B. et al. 2006), manufacturing residues, including chips and sawdust used for pulpwood, increased steadily from 1965 to 1996, peaking in 1988 with 435,000 cords (174,000 tons) in West Virginia (Figure 3.5). Manufacturing residues used for pulpwood production decreased 39% from 435,000 (174,000 tons) in 1988 to 267,000 cords (106,800 tons) in 1991, increased to 393,000 cords (157,200 tons) in 1995, and then decreased dramatically by 63% from 393,000 (157,200 tons) in 1995 to 146,000 cords (58,400 tons) in 2001.

![Figure 3.5 Pulpwood production from manufacturing residues, 1965 to 2001.](Source: Hansen B. et al. 2006)

### 3.2.2 Tools for Mill Residue Identification and Analysis

A computer decision model for economic evaluation of a residue system was developed in West Virginia to examine the economic feasibility of installing a sawmill residue fueled boiler (Walton et al. 1987). The program was written in the BASIC programming language. Model inputs include equipment configuration, lumber/residue production and market, cost factors, tax and projected inflation rates. Model outputs are current and expected revenues, energy available from current residues, yearly and itemized cash flow summaries. Commonly used economic decision criteria were adopted in the model including net present value (NPV), internal rate of return (IRR), payback period, benefit/cost ratio (B/C), return on invested capital (ROI), and average net pre-tax profit and average ROI over 10 years. Additionally, the program features an interactive user-defined sensitivity analysis, which allows the user to change the values of any or all of the input variables to determine the effect of each variable of interest on the economic criteria. The model was developed specifically for sawmills in West Virginia and its accuracy mainly depended on the quality of input data.
Another program was developed (Brock et al. 1987) to evaluate investment opportunities in cogeneration at sawmills and to use it to calculate NPV for three actual cases and some hypothetical cases applicable to West Virginia. Since there were no cogenerating sawmills operating in West Virginia at the time of study, three actual case studies, firms A, B, and C, were selected from neighboring states. For the hypothetical cases, four sawmill size classes with annual production of 15, 10, 5, and 1 million board feet (mmbf) were assumed to operate in West Virginia. It was also assumed that sawmills with annual production of more than 15 mmbf would produce excess electricity for sale while meeting all of its own needs for power. However, for other sizes of sawmills, a small amount of electricity would be available for sale but the main objective would be to satisfy the firm’s own needs for power. Model input includes equipment installation costs, plant construction costs, and other operating and maintenance costs. Model output is a cash flow table showing an array of returns and costs with a 20-year planning horizon covering the variables of revenues, expenses, depreciation, interest, taxes paid, and net after tax profit.

The Hardwood Trader developed by the Appalachian Hardwood Center (AHC) at West Virginia University has been used to identify mill residue availability in West Virginia, based on industry reported waste production (Bragonje et al. 2005). This web-based program can be used as a service to the forest products industry in West Virginia and surrounding states. The Hardwood Trader identifies available wood by-products within a specific radius of any town in West Virginia. Three modules of residue finder, residue links, and residue maps were included in the website. With the residue finder, the user could easily find out the residue production data (type and amount) of all the counties in West Virginia between 2002 and 2005. Users of the Hardwood Trader can locate additional sources of information related to wood residues including products, technical articles, publications, trade journals and newsletters, and processing equipment by accessing the residue links. Residue maps provide distribution map of residue available and total residue production within 5 and 10 mile radius around producers.

### 3.3 Agriculture Residues

Based on a survey conducted in the eastern panhandle of West Virginia (Basden et al. 1994), 53% of the litter producers that accumulated 101-400 tons/year of litter had a manageable amount that could be stored in a shed or under a tarp without difficulty. Twenty-seven percent of the producers accumulating 401-800 tons/year had a greater challenge for storing, applying and/or selling this quantity of litter (Basden et al. 1994). Of all the litter producers, 33% indicated that they used all of their litter, 52% used some and 15% used none (Figure 3.6a). For those who used their litter, 44% reported that more than 76% of their litter could be utilized while around 30% of them indicated that less than 25% of the litter was used (Figure 3.6b). For on-farm litter utilization, the 91% was used as fertilizer and only 8% was used for feed supplement. For the litter used for fertilizer, 82% was used on grassland and 16% was used on row crops. Approximately 66% of producers surveyed used more than 75% of their litter on grassland (Figure 3.7a), while only 6% of the producers used more than 50% of their litter on row crops (Figure 3.7b). Among the litter producers, 60% of them sold at least 76% of their litter as fertilizer.
Figure 3.6 Percentage of on-farm litter utilization.
(Source: Basden et al. 1994)
Basden et al. (1994) indicated that 27% of the litter producers sold none or kept all litters produced, 57% of the producers used some or sold some, and 16% sold all or used none of their litter. Producers are currently marketing 46% of the litter that is produced at their operation. About 46% of the producers indicated that they sold or gave away their litter, with 73% of the litter sold as fertilizer and 21% sold as a feed supplement. Of the litter sold for fertilizer, 60% of the producers sold more than 76% of their litter as fertilizer and 19% of them sold 26–50% of their litter as fertilizer (Figure 3.8a). On the other hand, 21% of producers sold 26–50% of their
litter for feed and only 10% of them sold more than 76% of their litters as feed (Figure 3.8b). Basden et al. (1994) also indicated that only 34% of the marketed litters were sold outside of the producers’ watersheds. One possible reason could be the relatively low market price for litter which prohibits long distance hauling (Bosch and Napit 1992).

Figure 3.8 Litter distribution to and utilization by non-poultry producers. (a) sold for fertilizer, (b) sold for feed.
(Source: Basden et al. 1994)
4. FEDERAL AND STATE POLICIES AND LAWS

4.1 Federal Policies and Laws

There are several federal policies and laws that are influencing biomass related research and development activities (Table 5.1). The Advanced Energy Initiative recently outlined by President Bush has set a national goal of replacing more than 75% of our oil imports from the Middle East by 2025 and provides for a 22% increase in clean-energy research at the Department of Energy (President Bush 2006). One focus is the Biorefinery Initiative – “to achieve greater use of homegrown renewable fuels in the United States and to help develop bio-based transportation fuels from agricultural waste products, such as wood chips, stalks, or switchgrass.” In 2000, the U.S. Congress enacted Title III of the Agricultural Risk Protection Act - the Biomass Research and Development Act of 2000, which brought new focus to public sector involvement in the conversion of biomass into biobased industrial products, including bioenergy (Duncan 2004). The USDA and DOE were designated as the lead departments in that effort. Under the 2002 Farm Bill (USDA Farm Bill Section 9006), the Renewable Energy and Energy Efficiency Program was proposed, which extends the Agricultural Risk Protection Act through the fiscal year 2007. The five-year program was designed to assist farmers, ranchers and rural small business with grants for renewable energy and energy efficiency projects. Congress has funded the program at $22.8 million per year for the first two years. In 2003 and 2004, a total of $44 million in grants were awarded to 281 projects in 33 states (http://www.rurdev.usda.gov/rbs/farmbill/index.html).

On May 17, 2001 the National Energy Policy was released. President Bush signed the National Energy Plan into a law in August, 2005, which provides $14.5 billion in tax breaks for bioenergy development (http://www.state.gov/e/eb/rls/fs/50876.htm). The policy addressed several issues including the diversification of America’s energy supply to include more alternative and renewable sources, encouraging energy efficiency and conservation, promoting more domestic production in environmentally responsible ways, and modernizing our electricity delivery system to minimize the risk of blackouts.

State Energy Alternatives were developed by the State and Local Initiatives group (SALI) at the National Renewable Energy Laboratory, in collaboration with the National Conference of State Legislatures. Programs in the Office of Energy Efficiency and Renewable Energy (EERE) at the U.S. Department of Energy provide the funding for related research/development activities (http://www.eere.energy.gov/states/alternatives/about.cfm).
Table 4.1  Major federal biomass related policies and laws.

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<th>Policy or law</th>
<th>Year</th>
<th>Web links or references</th>
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</tbody>
</table>

4.1.1 Public Utility Regulatory Policies Act of 1978

The Public Utility Regulatory Policies Act of 1978 (PURPA) was the most significant section of the National Energy Act in fostering the development of facilities to generate electricity from renewable energy sources. The PURPA opened the door to competition in the U.S. electricity supply market by requiring utilities to buy electricity from qualifying facilities (QFs). The QFs are defined as nonutility facilities that produce electric power using cogeneration technology, or power plants no greater than 80 megawatts of capacity that use renewable energy sources.

The Federal government, in formulating regulations, often delegates implementation to the States. This occurred with the PURPA, as the Federal Energy Regulatory Commission (FERC) delegated the authority for the determination of avoided cost to the States. In several States including California, avoided cost purchase contracts were very favorable to non-utility generators. For example, between 1982 and 1988, Standard Offer 4 (SO4) contracts written in California allowed the QFs to sell renewable energy under 15 to 30 year terms. The contract guarantees fixed payment rates (based on forecasted short-run avoided costs) for up to 10 years if the QF has signed a contract for at least 20 years. The 10-year provisions were tied to forecasts
of increases in oil and gas prices, and were the basis for the fixed payments for the first ten years of the contracts. Therefore, a price and revenue drop occurred in the eleventh year when the fixed contract energy prices converted to variable prices (based on short-term avoided cost), greatly lessening the economic viability of affected projects.

Two new financial incentives were introduced in the Energy Policy Act of 1992. One is known as a production tax credit (PTC), which is a 1.5 cents/kWh payment. It is payable for 10 years to private and investor-owned electric utilities for electricity from wind and closed-loop biomass facilities. The second is the renewable energy production incentive (REPI). This incentive allows a 1.5 cent/kWh, but is subject to annual congressional appropriations, for generation from biomass, wind, and solar energy. This incentive can be used by publicly owned utilities, local and county governments, as well as rural cooperatives.

There are four Federal tax subsidies for the production and use of alcohol as transportation fuels. The first being a 5.4 cent/gallon excise tax exemption. The second is a 54 cents/gallon blender’s tax credit. Thirdly, a 10 cents/gallon small ethanol production tax credit. Finally an alternative fuels production tax.

4.1.2 Executive Order 13134 1999

Executive Order 13134 in 1999 stated that current biobased products and bioenergy technology have the potential to make renewable farm and forestry resources major sources of affordable electricity, fuel, chemicals, pharmaceuticals, and other materials. Technical advances in these areas can create an expanding array of exciting new business and employment opportunities for farmers, foresters, ranchers, and other businesses in rural America. These technologies can create new markets for farm and forest waste products, new economic opportunities for underused land, and new value-added business opportunities. They also have the potential to reduce our Nation's dependence on foreign oil, improve air quality, water quality, and flood control, decrease erosion, and help minimize net production of greenhouse gases. It is the policy to develop a comprehensive national strategy, including research, development, and private sector incentives, to stimulate the creation and early adoption of technologies needed to make biobased products and bioenergy cost-competitive in large national and international markets.

4.1.3 Biomass Research and Development Act

The Title III – Biomass Research and Development Act of 2000 was revised by the Energy Policy Act of 2005. The objectives of this act were to develop technologies and processes for commercial production of biobased fuels and produce biobased products while providing a sustainable source for the production of these products. Purposes of this act include: the increase of energy security of the United States, job creation and economic development, enhance environment and public health, and market diversification for raw agricultural and forestry products.
The focus areas of the act include:

(1) Producing feedstock through the development of crops relevant to production of raw materials for conversion to biobased fuels and products: (a) crops with enhanced productivity, wider site range, and low requirements for chemical inputs, (b) advanced crop production methods to achieve features in (a), (c) feedstock harvest, handling, transport, and storage, (d) strategies for integrating feedstock production into existing managed land.

(2) Overcoming recalcitrance of cellulosic biomass through developing technologies for converting cellulosic biomass into intermediates that can subsequently converted into biobased fuels and biobased products. To diversify products through available technologies relevant to production of a range of biobased products.

(3) Providing strategic guidance for the application of biomass technologies in accordance with realization of improved sustainability and environmental quality, cost effectiveness, security, and rural economic development.

The Sec.310.[7 U.S.C. 7624 note] of the Act mentioned that there are authorized to be appropriated to carry out this title $200,000,000 for each of fiscal years 2006 through 2015.

4.1.4 Farm Bill 2002

The Title IX – Energy of the Farm Bill provides support for increased use of biomass-based energy and products and for biomass related research and development. The follows briefly summarize five of the 10 sections under the Title IX:

(1) Section 9003 - Biorefinery development grants. It is to assist in the development of new and emerging technologies for the use of biomass including lignocellulosic biomass. The amount of a grant for a project awarded under this section shall not exceed 30% of the project.

(2) Section 9004 - Biodiesel fuel education program. There are authorized to be appropriated $1,000,000 to carry out this section for each of fiscal years 2003 through 2007.

(3) Section 9005 - Energy audit and renewable energy development program. A recipient of a grant under this section that conducts an energy audit for a farmer, rancher, or rural small business shall require that, as a condition of the energy audit, the farmer, rancher, or rural business pays at least 25% of the cost of the audit.

(4) Section 9006 – Renewable energy systems and energy efficiency improvements. It is to make loans, loan guarantees, and grants to farmers, ranchers, and rural small business to purchase renewable energy systems and make energy efficiency improvements. There is $23,000,000 available for each of fiscal years 2003 through 2007. The amount of a grant shall not exceed 25% of the cost of the activity funded under this section. The combined amount of a grant and loan made or guaranteed shall not exceed 50% of the cost of the activity funded under this section.

(5) Section 9008 – Biomass research and development. It is the same as Biomass Research and Development Act of 2000 in 5.1.3.
4.1.5 Farm Security and Rural Investment Act of 2002

The Farm Security and Rural Investment Act (FSRIA) of 2002 is the Farm Bill 2002 provision. The Act is landmark legislation for conservation funding and for focusing on environmental issues. The conservation provisions help farmers and ranchers meet environmental challenges on their land. This legislation simplifies existing programs and creates new programs to address high priority environmental and production goals. The 2002 Farm Bill enhances the long-term quality of our environment and conservation of our natural resources.

FSRIA allows for development of a procurement program for biobased products where federal agencies are required to purchase these products. The Act calls for purchasing of products when the designated item costs over $10,000 or when the quantities of functionally equivalent items purchased over the preceding fiscal year equaled $10,000 or more. Federal agencies are required to purchase biobased products except when the items are not reasonably available, fail to meet applicable standards, or are unreasonably priced. The USDA and Office of Federal Procurement Policy (OFPP) work to ensure these requirements of Section 9002 of the Federal Acquisition Regulation.

4.1.6 Healthy Forests Initiative

The protocols for the Healthy Forests Act call for: (1) Improving procedures for developing and implementing fuels treatment and forest restoration projects in priority forests and rangelands, in collaboration with local governments; (2) Reducing the number of overlapping environmental reviews by combining project analysis and establishing a process for concurrent project clearance by federal agencies; (3) Developing guidance for weighing the short-term risks against the long-term benefits of fuels treatment and restoration projects; and (4) Developing guidance to ensure consistent NEPA procedures for fuels treatment activities and restoration activities, including development of a model Environmental Assessment for these types of projects.

The plan specifically calls for active forest and rangeland management, including thinning of forests and rangelands that produce forest by-products, biomass removal and utilization, and other tools that will meet long-term ecological, economic, and community objectives.

4.1.7 Comprehensive Federal Energy Legislation - the 2005 Final Bill

This Bill contains tax incentives for many energy efficiency and supply technologies. These incentives totaled approximately $2.3 billion in the final bill, which was down from about $5.5 billion submitted in the Senate Bill. Incentives are included for:

- High-efficiency vehicles, either hybrid or diesel, with credits on a sliding scale based on efficiency; maximum credit for light-duty vehicles expected to be about $3,400 for Prius-level performance.
- New homes, with $2,000 for builders making homes using 50% less energy than the International Energy Conservation Code (IECC) and $1,000 for manufactured homes meeting ENERGY STAR® criteria.
- Existing homes, with 10% of cost up to a $500 limit for:
  - Insulation and envelope improvements meeting IECC specifications
- Windows meeting IECC specifications, with a cap of $200 per homeowner
- Central air conditioners or heat pumps meeting 2006 Consortium for Energy Efficiency specifications, capped at $300
- Furnaces and boilers with Annual Fuel Utilization Efficiency of 95 or better, capped at $150
- Water heaters with Energy Factor of .80 or better, capped at $300
- Heat pump water heaters with an Energy Factor of 2.0 or better, capped at $300
- Ground source heat pumps meeting specified performance levels, capped at $300

- Commercial buildings, with a $1.80 per square foot deduction for buildings exceeding ASHRAE 90.1-2001 standards by 50% or more, with prorated deductions available for individual systems.
- Manufacturer credits for high-efficiency appliances (including refrigerators, clothes washers, and dishwashers) of up to $175, with a per-manufacturer cap of $75 million over the credit period.

4.1.8 The Energy Policy Act 2005

There are 16 titles in the 2005 Energy Policy Act, which ensures a more affordable and environmentally friendly energy supply, provides direction on program content as well as loan guarantee authorization for commercial scale demonstrations. Following are the highlights of four titles:

(1) Title I – Energy Efficiency. It provides funding for energy efficiency programs for public buildings, including schools and hospitals, and increases fuel efficiency requirements for federal vehicles. Title I also authorizes $3.4 billion for each fiscal year 2005 through 2007 for the Low Income Housing Assistance Program (LIHEAP) and increases funding for low-income weatherization programs and state energy programs to improve energy efficiency. Permanently authorizes the Energy Savings Performance Contracts program with conditions on the number of federal agencies (3 - DOE, DOD, VA) and number of contracts (100) so that the program does not score above $500 million. It requires coordinators to enforce contract caps.

(2) Title II – Renewable Energy. This Title reauthorizes the Renewable Energy Production Incentive program to provide renewable energy production incentives for solar, wind, geothermal, biomass and expands it to include landfill gas. It also authorizes $100 million for increased hydropower production through increased efficiency at existing dams and modernizes the nation’s hydropower laws to allow increased production, without compromising existing environmental protections. Hydroelectric power is our nation’s single largest renewable energy source and accounts for roughly 10 percent of our electricity supply. This Title II also directs the federal government to use more renewable energy, with a goal of using 7.5% or more by 2013.

(3) Title IX – Studies and Program Support. Specific authorizations are provided for energy-efficiency efforts, a next-generation lighting initiative, national building performance initiative, programs regarding renewable energy, bioenergy and solar power. The Title authorizes almost $4 billion for energy and conservation activities; more than $3 billion in funding over the next five years for renewable energy efforts; and more than $2.5 billion for fossil fuel efforts.
(4) Title XV – Ethanol and Motor Fuels. This Title intends to establish a Renewable Fuels Standard of 5 billion gallons to be introduced into the marketplace by 2010. It also authorizes $380 million per year, through fiscal year 2009, for general administration, operator training and enforcement activities, cleanups of gasoline or chemical contaminated sites, cleanups of ether fuel additives in gasoline, inspection programs and requirements, and for release prevention, compliance, and enforcement activities.

4.2 State Policies and Laws

There are few biomass related policies and laws available in West Virginia. Table 4.2 summarizes some of them.

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4.2.1 The West Virginia Public Energy Authority

The West Virginia Public Energy Authority (WVPEA) was created by legislation in 1985 and continued in 2005. The PEA is authorized to foster, encourage and promote the establishment and operation of coal-fired electric generation facilities, electric and natural gas transmission infrastructure and other energy projects as well as engage in strategic planning to enable West Virginia to cope with changes affecting the industry. The PEA has the authority to issue revenue bonds for or acquire and finance electric power projects and electric natural gas transmission projects.

4.2.2 Logging Sediment Control Act 1992

The West Virginia Logging Sediment Control Act (LSCA) was passed in 1992 in response to public concerns about timber harvesting operations in West Virginia. The intent of the LSCA was to improve general logging practices thereby reducing erosion and stream sediment. The LSCA was issued to target people and companies involved in harvesting timber, or buying logs for resale. The West Virginia Division of Forestry (WVDOF) was designated by the WV State Legislature as the agency responsible for carrying out the mandates and provisions of LSCA, and conducting supervision and enforcement of BMPs.
There are 14 sections in this Act. Sections 19-1B-4 and 19-1B-6 require loggers to obtain a timbering license and provide operation notification and on-site job posting within three days of starting the harvesting operations (WVDOF 2005). Reclamation of the job is to be completed within 7 days of the completion date of the logging job. Section 19-1B-7 of the Act also requires that each logging job be supervised by a certified logger. To be a certified logger in West Virginia, an individual needs to have successfully completed training classes in first-aid, BMPs and logging safety. Section 19-1B-5 of LSCA especially authorizes WVDOF field foresters to issue compliance orders if a logging practice has the potential to cause or contribute to soil erosion or water pollution. The WVDOF has to follow up with enforcement on not only logging activities, but also the previously mentioned requirements.

4.2.3 Solid Waste Management

Title 33 and Series 1 of the Legislative Rule of WV Department of Environmental Protection are the Solid Waste Management Rule. The Solid Waste Management Rule states that waste must be disposed, processed, stored, transferred, or recycled only at a permitted solid waste facility. It is illegal to dispose of any waste on lands that are not regulated or licensed. This action may lead to water, land, or air pollution.

To protect against the migration of explosive gases such as methane from the landfill, the West Virginia Solid Waste Management Rule requires the collection of LFG in some situations. The WVDEP Secretary has the authority to require passive LFG vents on disposal areas that have neither received waste in six months nor will receive waste in one year, to control methane and other explosive gases. At least one gas vent per acre would be required and landfills must monitor for LFG at least quarterly. Necessary steps are also required to remedy the problem when dangerous LFG concentrations are present. When landfills or cells within them are closed, operators must install LFG management systems with at least one passive gas vent per acre (Hansen E. et al. 2006).
5. BIOMASS RESEARCH AND UTILIZATION OPPORTUNITIES

5.1 Biomass Conversion Technologies

As early as the 1970s, it was recognized that wood is not an ideal industrial fuel since it is solid, of modest heat content, frequently wet, and bulky to transport (Jamison 1979). However, Jamison (1979) also stated that the benefits of wood fuel could be upgraded by drying, screening, grinding, and densifying or pelletizing. Good practices of wood residue handling and preparation could significantly reduce the total delivered cost of wood fuel. Drying to reduce moisture content of wood residue is one way to lower transportation costs and improve energy conversion efficiency (Patterson and Zinn 1990). Densification or pelletization of wood residues also helps lower transportation and storage costs. The process consists of reducing wood residue material to approximately sawdust-sized particles, drying to 10-18% moisture content, and then densifying the feedstock in an extruder (Patterson and Zinn 1990).

Most of the previous research in renewable energy has concentrated on agricultural crops or wastes for producing bio-based transportation fuels (Brown 2003). Wood has not received as much attention as a resource for its transformation to useful bioproducts or as a starting material for other industrial uses because its conversion was not considered to be economically viable until recently (Sedjo 1997). Few technologies, including both biochemical and thermal processes, have been investigated for converting wood residues to produce gaseous, liquid and solid fuels as substitute for fossil fuels (Figure 5.1). Some efforts in the utilization of wood-based residues have been in the manufacture of wood pellets for energy and co-generation of electricity by burning coal with wood. Wood contains low sulfur content and can be used to reduce sulfur dioxide emissions produced by coal fired energy production plants. In addition, wood reduces the amount of fossil carbon dioxide emissions and allows producers to meet the voluntary carbon dioxide reduction plans, such as the Climate Change Action Plan. Experiments indicate that approximately 4 percent (BTU basis) of coal can be replaced by wood residues without adding additional wood handling and feeding equipment. The Virginia Biomass Energy Program estimates that if annual sawdust and logging residue production were combined with the annual growth of low-quality unmerchantable trees, enough biomass exists to provide 42 percent of Virginia’s industrial and commercial oil and gas consumption needs (http://www.serbep.org/).

Wood residues can be burnt directly for heat and electricity or can be converted into solid, liquid or gaseous fuels using conversion technologies such as carbonization, gasification, fermentation, and wood densification (AFPA 2006). Carbonization concentrates the carbon in wood, and reduces both weight and volume of wood into easily transportable and storable form (Satonaka 1982).

5.1.1 Combustion and Gasification

Biomass combustion, such as burning wood, has been one of man's primary ways of deriving energy from biomass from prehistoric times to the present. It is not, however, very efficient. Converting the solid biomass to a gaseous or liquid fuel by heating it with limited oxygen prior to combustion can greatly increase the overall efficiency, and also make it possible to instead convert the biomass to valuable chemicals or materials (USDOE 2006). Patterson and Zinn (1990) detailed wood gasification, which is an oxidation/pyrolysis process by which wood
cellulose, hemicellulose, and lignin are broken down into simpler chemical components, including both gases and volatile liquids. A complete wood gasification system consists of fuel storage, handling, preparation and drying equipment, blowers, piping, and monitoring and control equipment for air and gas, ash handling and disposal equipment, and gas cooling and cleaning equipment (Overend 1979). The U.S. Department of Energy Biomass Program has made a national effort to develop thermochemical technologies to more efficiently tap the enormous energy potential of lignocellulosic biomass. In addition to gasification, pyrolysis, and other thermal processing, the cleaning up and conditioning the converted fuel has been focused on by the program (Figure 5.1).

Some manufacturing facilities are also installing co-generation systems to produce electricity to operate their plants. Cogenerated electricity is cheaper than commercial electricity because the energy lost at commercial plants in condensing is used as process steam in the cogenerating facility (Patterson and Zinn 1990). In the United States, wood biomass electrical power generation experienced dramatic growth with more than tripled wood biomass-based generating capacity in the late 1970s and early 1980s as a direct result of federal tax policy and state utility regulatory actions (Skog and Rosen 1997). The DOE and USDA have initiated a joint program emphasizing using existing forest and mill residues specifically for power production and the use of dedicated feedstock systems and advanced combustion technologies. Procurement of a guaranteed supply of fuel at a competitive price within a reasonable radius of a power plant has been a major stumbling block for electrical power generation from biomass. Based on the location of existing coal-fired plants that could be replaced or co-fired with biomass feedstock, the available land area and quality to produce forest biomass are essential (Skog and Rosen 1997).

Chemical catalysis uses an added but not consumed substance to augment a chemical reaction. Catalytic conversion will be a primary tool for industry to produce valuable fuels, chemicals, and materials from biomass in the future. Catalytic conversion of biomass is best developed for synthesis gas or syngas. Syngas is a mixture of carbon monoxide and hydrogen. Proven catalytic processes for syngas conversion to fuels and chemicals exist and these can be applied to the production of fuels and chemicals from biomass via gasification. Syngas produced by gasification of fossil fuels or biomass can be converted into a large number of organic compounds that are useful as chemical feedstocks, fuels and solvents. At the center of this transformation is a selective catalyst that works under heat and pressure to convert the carbon monoxide and hydrogen into larger, more useful compounds. Many of the conversion technologies were developed for coal gasification and process economics have resulted in a shift to natural-gas-derived syngas. These conversion technologies, however, apply similarly to biomass-derived syngas (USDOE 2006).

Densification of wood residues is another way to increase their heating value and make them efficient to transport and store. A number of methods exist for densifying wood fuels (Resch 1982), however they usually involve subjecting sawdust, wood chips and similar material, and subjecting them to heat and pressure in a mold to form briquettes or pellets (AFPA 2006).
Figure 5.1 Biomass conversion technologies.
(Sources: Smith 2004, Perlack et al. 2005, Patterson and Zinn 1990)
5.1.2 Fermentation

Fermentation is the process of deriving ethanol from the sugars found in wood. It first involves removing the lignin from wood, in order to unlock the cellulose and hemicellulose for subsequent hydrolysis into fermentable sugars, either by acid-catalysis or using enzymes (AFPA 2006). Ethanol is desirable as an oxygenate for gasoline. In the early 1990s, a method was reported to convert cellulose and hemicellulose to sugars by dilute or concentrated acid-catalyzed hydrolysis and then ferment the hexose sugars to ethanol (Lynd et al. 1991). Technologies were later developed to hydrolyze wood with enzymes and to convert pentose as well as hexose sugars to ethanol (Skog and Rosen 1997). Another method of simultaneous saccharification and fermentation for ethanol production was developed by the Department of Energy’s National Renewable Energy Laboratory in Colorado and is currently being tested in pilot plants (Skog and Rosen 1997).

Herbst et al. (2003) conducted a financial feasibility study of lignocellulosic ethanol process by using capital budgeting analysis with consideration of risk. They concluded that lignocellulosic-based ethanol production could be a profitable enterprise compared to maize-based ethanol production under certain economic conditions. An economic modeling of a lignocellulosic biomass biorefining industry was carried out (Epplin 2004) to determine the source, size, and operating factors of the plant.

5.1.3 Biorefinery

Small-scale preliminary studies have tested the potentials of biomass gasification and liquid pyrolysis using short rotation forest and wood chips. Although advanced technologies for producing fuel from woody biomass have been developed at the research stage, none of these technologies has become commercially viable. The environmental effects and economic feasibility for conversion of wood residues into bioenergy are not well documented.

There are many companies now, which produce biodiesel fuel. Likewise, the number of plants that produce bioenergy is also growing across the nation. These alternatives are becoming more abundant where source materials are located. Biodiesel can be generated from many crops. These include soybean, rapeseed, corn, safflower, and some animal fats as well. The production of biodiesel, or alkyl esters, is well known (Figure 5.2). There are three basic routes to ester production from oils and fats (Figure 5.3): (1) Base catalyzed transesterification of the oil with alcohol; (2) Direct acid catalyzed esterification of the oil with methanol; (3) Conversion of the oil to fatty acids, and then to Alkyl esters with acid catalysis (NBB 2006). Eidman (2004) stated that the U.S. consumed 39,930 million gallons of diesel fuel per year. They suggest that mixing 5% biodiesel and diesel fuel would require 1,996.5 million gallons of biodiesel.
Biorefining is a process that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass (NREL 2006). Figure 5.4 illustrates the process of a biorefinery with input and output. This system can be applied to a variety of needs, including heating and energy that can be distributed to homes or municipalities. The cost factors depend on the size of the system installed, and also on the products used for input.
5.1.4 Available Systems

Bioenergy is also an increasing option for people or communities who want to be self-sufficient for their electricity and heat production. The Community Power Corporation (CPC) manufactures equipment that can produce heat and energy from waste products including wood pellets, wood chips, and nut shells (www.cpc.com). These systems are capable of producing 5 to 100 KW depending on the size of the system. The ratings for thermal power range from 50 – 500 KBTU per hour. The system weighs 1,500 lbs and the specifications show the footprint to be 5 m by 5 m. The structure to house this unit should be at least 14 ft tall. The system appears to take up minimal space and a building that is 35 ft by 30 ft. There is additional space required for long-term storage of feedstock.

The Advanced Alternative Energy Corp. (AAEC) produces furnaces for small scale heating or power generation (www.aaecorp.com). Their furnaces are designed to utilize low grade wood and other types of biomass such as wood chips, cobs, pellets, briquettes, and compacted household trash. The furnace system can be automated to be self-stoking with many types of fuels including natural gas, fuel oil, waste oil, paper, shredded wood, corn cobs, baled weeds, fuel crops or agri-products (AAEC 2006). The AAEC recently introduced a new system for waste and biomass combustion called Sequential Grates Combustion System. This new system is well suited for utilizing various household and industrial wastes, biomasses and/or fossil fuels. Any combination of these may be utilized in this new system for heat or electrical power generation. Incorporated in the system is an automatic in-feed conveyor that feeds a holding hopper that in turn "batch stokes" solid fuels onto grates within the combustion unit itself. These fuels are then ignited and dropped from grate to grate while burning, until completely converted to ash, which is then removed automatically for processing. Air emissions abatement is achieved using a novel combination of smoke re-circulation and other pollution abatement technologies. This innovative combination of abatement technologies is a more economical and appropriate control technology for the next generation of combustion systems. Many innovative advantages are inherent in this completely new system including: (1) automatic, co-firing, stoking and de-ashing of any combination of solid, liquid or gaseous fuels, in a single,
dependable and effective system, with successively starved, neutral and excess air combustion, in a single combustion chamber, using gravity for dependable and "sequential" fuels stoking movement; (2) cleaner burning with lower "upstream" and "downstream" costs by lowering the upstream fuels pre-conditioning costs and downstream pollution abatement costs; and (3) co-fires any combination of fuels including, whole tires, broken pallets, coal, gas, oil, municipal solid waste, industrial waste, whole tree material, lumbering residues, loose or baled agri-byproducts, with low cost pollution abatement via smoke re-circulation.

5.2 Potential Research/Development Opportunities

Renewable energy from biomass has the potential to reduce dependency on fossil fuels, though not to totally replace them. Realizing this potential will require the simultaneous development of appropriate biomass collection and process systems, high yielding biomass production systems and bioconversion technologies that can efficiently convert biomass energy into the forms of energy and chemicals usable by industry (McLaughlin et al. 1999).

Appropriate handling systems must be developed to make biomass utilization more efficient (Luppold and Bumgardner 2003). Currently, the most cost-effective system to recover forest residue for biomass is in-woods chipping as part of conventional timber harvesting (Hartsough et al. 1997). In-woods chipping systems, however, are not effective when ground-based extraction is restricted or when there are no merchantable products other than biomass (Rummer et al. 2004). Based on the cut-to-length systems, biomass collection systems have been developed in Scandinavian countries for many years. Biomass bundlers collect, compress, and bind forest residues into cylindrical bundles of log forms, which can also make biomass handling more cost-effective and needs to be evaluated in central Appalachian region (Figure 5.5).

Figure 5.5 Slash bundler by John Deere.
Although some technologies exist for converting biomass to bioenergy or bioproducts, there are still many uncertainties in the technology and economic feasibilities including conversion rate, cost of the feedstock, cost of the cellulose enzyme, and other factors. New technology in lignocellulosic biomass processing should focus on developing cellulose enzymes that provide higher and more rapid conversion and development of biorefineries capable of producing a range of products such as liquid, fuels, power, and chemicals (Eidman 2004). Additionally, the feasibility of biofuel and bioproduct production facility needs to be further addressed.

Improvements in conversion efficiency and cost effectiveness of biobased products and bioenergy are needed to further reduce production costs and increase the market competitiveness of biomass. For example, the economic feasibility of anaerobic digesters usually rests on reducing an expense for disposal of waste and substitution of the gas produced for purchased fuel and/or use of the gas to generate electricity. The challenges of the perennial crops, such as switchgrass, have been to combine the near-term objectives of maximizing potential current economic yields with the longer term objectives of improving and protecting yields through breeding and biotechnology (Sanderson and Wolf 1996).

Integrated biorefineries are another potential research area, which would convert biomass into a variety of fuels, chemicals, materials and power, such as petrochemical refineries. Existing industries such as wet-mill corn processing and pulp and paper mills fit the multiple-products-from-biomass definition of a biorefinery, but the goal is to foster new industries converting lignocellulosic biomass into a wide range of products, including ones that would otherwise be made from petrochemicals. As with petrochemical refineries, the vision is that the biorefinery would produce both high-volume liquid transportation fuel (meeting national energy needs) and high-value chemicals or products (enhancing operation economics) (USDOE 2006). Sugar platform biorefineries would likely convert biomass into different types of component sugars for fermentation or other biological processing into various fuels and chemicals. Thermochemical biorefineries would likely convert biomass to synthesis gas (hydrogen and carbon monoxide) or pyrolysis oil, the various components of which could be directly used as fuel or converted to other fuels and chemicals by chemical catalysis (USDOE 2006).

Some efforts in the utilization of wood-based residues have been in the manufacture of wood pellets for energy and co-generation of electricity by burning coal with wood. It is possible to convert biomass into potential biofuels and bioproducts using various other procedures that are more environmentally sustainable and energetically efficient. We can continue to enhance the traditional utilization of biomass in West Virginia, using small scale community heating, and steam production for industrial centers. However, new opportunities exist for the state of West Virginia in the development and adaptation of technologies such as biomass gasification, liquid pyrolysis, and biorefining for the manufacture of biofuels, biochemicals, and biopolymers from abundant bio-based materials. The potential markets and industrial development related to biomass needs to be readdressed in the state. Development of a demonstration project seems necessary to show communities and civic leaders how economically, environmentally, and sustainably biomass can be utilized.
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APPENDIX A: GLOSSARY
(Source: http://bioenergy.ornl.gov/faqs/glossary.html)

Anaerobic digestion: Decomposition of biological wastes by micro-organisms, usually under wet conditions, in the absence of air (oxygen), to produce a gas comprising mostly methane and carbon dioxide.

Barrel of oil equivalent: (boe) The amount of energy contained in a barrel of crude oil, i.e. approximately 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. A "petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 liters); about 7.2 barrels are equivalent to one tonne of oil (metric).

Biochemical conversion: The use of fermentation or anaerobic digestion to produce fuels and chemicals from organic sources.

Bioenergy: Useful, renewable energy produced from organic matter. The conversion of the complex carbohydrates in organic matter to energy. Organic matter may either be used directly as a fuel or processed into liquids and gases.

Biofuel: See biomass fuel.

Biogas: A combustible gas derived from decomposing biological waste under anaerobic conditions. Biogas normally consists of 50 to 60 percent methane. See also landfill gas.

Biomass: Organic matter available on a renewable basis. Biomass includes forest and mill residues, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes.

Biomass fuel: Liquid, solid, or gaseous fuel produced by conversion of biomass. Examples include bioethanol from sugar cane or corn, charcoal or woodchips, and biogas from anaerobic decomposition of wastes.

Biomass energy: See Bioenergy.

Biorefinery: A biorefinery is a facility that integrates biomass conversion process and equipment to produce fuels, power, and chemicals from biomass.

Board Foot: The amount of wood contained in an unfinished board 1 inch thick, 12 inches long and 12 inches wide. Abbreviated “BF”. Common units as related to saw log volume measurement include – 1,000 BF or MBF and 1,000,000 BF or MMBF.

Bone dry: Having zero percent moisture content. Wood heated in an oven at a constant temperature of 100°C (212°F) or above until its weight stabilizes is considered bone dry or oven dry.
**Bottoming cycle:** A cogeneration system in which steam is used first for process heat and then for electric power production.

**British thermal unit:** (Btu) A non-metric unit of heat, still widely used by engineers. One Btu is the heat energy needed to raise the temperature of one pound of water from 60°F to 61°F at one atmosphere pressure. 1 Btu = 1055 joules (1.055 kJ).

**Capacity:** The maximum power that a machine or system can produce or carry safely. The maximum instantaneous output of a resource under specified conditions. The capacity of generating equipment is generally expressed in kilowatts or megawatts.

**Capital cost:** The total investment needed to complete a project and bring it to a commercially operable status. The cost of construction of a new plant. The expenditures for the purchase or acquisition of existing facilities.

**cfm:** Cubic feet per minute (1000 cfm = 0.472 cubic meters per second, m³/s)

**Cellulose:** The principal chemical constituent of cell walls of plants: a long chain of simple sugar molecules.

**Char:** The remains of solid biomass that has been incompletely combusted, such as charcoal if wood is incompletely burned.

**Chipper:** A machine that produces wood chips by knife action.

**Chips:** Woody material cut into short, thin wafers. Chips are used as a raw material for pulping and fiberboard or as biomass fuel.

**Conifer:** Tree, usually evergreen, with cones and needle-shaped or scalelike leaves, producing wood known commercially as softwood.

**Cogeneration:** The sequential production of electricity and useful thermal energy from a common fuel source. Reject heat from industrial processes can be used to power an electric generator (bottoming cycle). Conversely, surplus heat from an electric generating plant can be used for industrial processes, or space and water heating purposes (topping cycle).

**Combined cycle:** Two or more generation processes in series or in parallel, configured to optimize the energy output of the system.

**Combined-cycle power plant:** The combination of a gas turbine and a steam turbine in an electric generation plant. The waste heat from the gas turbine provides the heat energy for the steam turbine.

**Combined heat and power:** (CHP) See Cogeneration.
**Combustion:** Burning. The transformation of biomass fuel into heat, chemicals, and gases through chemical combination of hydrogen and carbon in the fuel with oxygen in the air.

**Combustion air:** The air fed to a fire to provide oxygen for combustion of fuel. It may be preheated before injection into a furnace.

**Combustion efficiency:** (actual heat produced by combustion) divided by (total heat potential of the fuel consumed)

**Commercial forest land:** Forested land which is capable of producing new growth at a minimum rate of 20 cubic feet per acre/per year, excluding lands withdrawn from timber production by statute or administrative regulation.

**Coppice regeneration:** The ability of certain hardwood species to regenerate by producing multiple new shoots from a stump left after harvest.

**Cord:** A stack of wood consisting of 128 cubic feet (3.62 cubic meters). A cord has standard dimensions of 4 x 4 x 8 feet, including air space and bark. One cord contains about 1.2 U.S. tons (oven-dry), i.e. 2400 pounds or 1089 kg.

**Corn stover:** Stalks that remain after corn has been harvested.

**Diameter at breast height:** (DBH) The diameter of a tree measured 4 feet 6 inches above the ground.

**Digester:** An airtight vessel or enclosure in which bacteria decomposes biomass in water to produce biogas.

**Discount rate:** A rate used to convert future costs or benefits to their present value.

**Downdraft gasifier:** A gasifier in which the product gases pass through a combustion zone at the bottom of the gasifier.

**Dutch oven furnace:** One of the earliest types of furnaces, having a large, rectangular box lined with firebrick (refractory) on the sides and top. Commonly used for burning wood. Heat is stored in the refractory and radiated to a conical fuel pile in the center of the furnace.

**Effluent:** The liquid or gas discharged from a process or chemical reactor, usually containing residues from that process.

**Emissions:** Waste substances released into the air or water. See also Effluent.

**Energy crops:** Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane, and nonfood crops such as poplar trees and switchgrass. Currently, two energy crops are under development: short-rotation woody crops, which are fast-growing
hardwood trees harvested in 5 to 8 years, and herbaceous energy crops, such as perennial grasses, which are harvested annually after taking 2 to 3 years to reach full productivity.

**Externality:** A cost or benefit not accounted for in the price of goods or services. Often "externality" refers to the cost of pollution and other environmental impacts.

**Feedstock:** Any material which is converted to another form or product.

**Feller-buncher:** A self-propelled machine that cuts trees with giant shears near ground level and then stacks the trees into piles to await skidding.

**Fermentation:** Conversion of carbon-containing compounds by micro-organisms for production of fuels and chemicals such as alcohols, acids or energy-rich gases.

**Firm power:** (firm energy) Power which is guaranteed by the supplier to be available at all times during a period covered by a commitment. That portion of a customer's energy load for which service is assured by the utility provider.

**Fluidized-bed boiler:** A large, refractory-lined vessel with an air distribution member or plate in the bottom, a hot gas outlet in or near the top, and some provisions for introducing fuel. The fluidized bed is formed by blowing air up through a layer of inert particles (such as sand or limestone) at a rate that causes the particles to go into suspension and continuous motion. The super-hot bed material increased combustion efficiency by its direct contact with the fuel.

**Fly ash:** Small ash particles carried in suspension in combustion products.

**Forest residues:** Material not harvested or removed from logging sites in commercial hardwood and softwood stands as well as material resulting from forest management operations such as precommercial thinnings and removal of dead and dying trees.

**Forest health:** A condition of ecosystem sustainability and attainment of management objectives for a given forest area. Usually considered to include green trees, snags, resilient stands growing at a moderate rate, and endemic levels of insects and disease. Natural processes still function or are duplicated through management intervention.

**Fossil fuel:** Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.

**Fuel cell:** A device that converts the energy of a fuel directly to electricity and heat, without combustion.

**Fuel cycle:** The series of steps required to produce electricity. The fuel cycle includes mining or otherwise acquiring the raw fuel source, processing and cleaning the fuel, transport, electricity generation, waste management and plant decommissioning.
**Fuel handling system:** A system for unloading wood fuel from vans or trucks, transporting the fuel to a storage pile or bin, and conveying the fuel from storage to the boiler or other energy conversion equipment.

**Furnace:** An enclosed chamber or container used to burn biomass in a controlled manner to produce heat for space or process heating.

**Gas turbine:** (combustion turbine) A turbine that converts the energy of hot compressed gases (produced by burning fuel in compressed air) into mechanical power. Often fired by natural gas or fuel oil.

**Gasification:** A chemical or heat process to convert a solid fuel to a gaseous form.

**Gasifier:** A device for converting solid fuel into gaseous fuel. In biomass systems, the process is referred to as pyrolytic distillation. See Pyrolysis.

**Genetic selection:** Application of science to systematic improvement of a population, e.g. through selective breeding.

**Gigawatt:** (GW) A measure of electrical power equal to one billion watts (1,000,000 kW). A large coal or nuclear power station typically has a capacity of about 1 GW.

**Greenhouse effect:** The effect of certain gases in the Earth's atmosphere in trapping heat from the sun.

**Greenhouse gases:** Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

**Grid:** An electric utility company's system for distributing power.

**Habitat:** The area where a plant or animal lives and grows under natural conditions. Habitat includes living and non-living attributes and provides all requirements for food and shelter.

**Hardwoods:** Usually broad-leaved and deciduous trees.

**Heat Rate:** The amount of fuel energy required by a power plant to produce one kilowatt-hour of electrical output. A measure of generating station thermal efficiency, generally expressed in Btu per net kWh. It is computed by dividing the total Btu content of fuel burned for electric generation by the resulting net kWh generation.

**Heat transfer efficiency:** useful heat output released / actual heat produced in the firebox

**Heating value:** The maximum amount of energy that is available from burning a substance.

**Hectare:** Common metric unit of area, equal to 2.47 acres. 100 hectares = 1 square kilometer.
Herbaceous: Non-woody type of vegetation, usually lacking permanent strong stems, such as grasses, cereals and canola (rape).

Higher heating value: (HHV) The maximum potential energy in dry fuel. For wood, the range is from 7,600 to 9,600 Btu/lb (17.7 to 22.3 GJ/t).

Horsepower: (electrical horsepower; hp) A unit for measuring the rate of mechanical energy output, usually used to describe the maximum output of engines or electric motors. 1 hp = 550 foot-pounds per second = 2,545 Btu per hour = 745.7 watts = 0.746 kW

Hydrocarbon: Any chemical compound containing hydrogen, oxygen, and carbon.

Incinerator: Any device used to burn solid or liquid residues or wastes as a method of disposal. In some incinerators, provisions are made for recovering the heat produced.

Inclined grate: A type of furnace in which fuel enters at the top part of a grate in a continuous ribbon, passes over the upper drying section where moisture is removed, and descends into the lower burning section. Ash is removed at the lower part of the grate.

Incremental energy costs: The cost of producing and transporting the next available unit of electrical energy. Short run incremental costs (SRIC) include only incremental operating costs. Long run incremental costs (LRIC) include the capital cost of new resources or capital equipment.

Independent power producer: A power production facility that is not part of a regulated utility.

Indirect liquefaction: Conversion of biomass to a liquid fuel through a synthesis gas intermediate step.

Joule: Metric unit of energy, equivalent to the work done by a force of one Newton applied over a distance of one meter (= 1 kg m2/s2). One joule (J) = 0.239 calories (1 calorie = 4.187 J).

Kilowatt: (kW) A measure of electrical power equal to 1,000 watts. 1 kW = 3,413 Btu/hr = 1.341 horsepower. See also watt.

Kilowatt hour: (kWh) A measure of energy equivalent to the expenditure of one kilowatt for one hour. For example, 1 kWh will light a 100-watt light bulb for 10 hours. 1 kWh = 3,413 Btu.

Landfill gas: A type of biogas that is generated by decomposition of organic material at landfill disposal sites. Landfill gas is approximately 50 percent methane. See also biogas.

Levelized life-cycle cost: The present value of the cost of a resource, including capital, financing and operating costs, expressed as a stream of equal annual payments. This stream of payments can be converted to a unit cost of energy by dividing the annual payment amount by the annual kilowatt-hours produced or saved. By leveling costs, resources with different lifetimes and generating capabilities can be compared.
**Lignin:** Structural constituent of wood and (to a lesser extent) other plant tissues, which encrusts the cell walls and cements the cells together.

**Megawatt:** (MW) A measure of electrical power equal to one million watts (1,000 kW). See also watt.

**Mill/kWh:** A common method of pricing electricity in the U.S. Tenths of a U.S. cent per kilowatt hour.

**Mill residue:** Wood and bark residues produced in processing logs into lumber, plywood, and paper.

**MMBtu:** One million British thermal units.

**Moisture content:** (MC) The weight of the water contained in wood, usually expressed as a percentage of weight, either oven-dry or as received.

**Moisture content, dry basis:** Moisture content expressed as a percentage of the weight of oven-dry wood, i.e.:

\[
\frac{\text{weight of wet sample} - \text{weight of dry sample}}{\text{weight of dry sample}} \times 100
\]

**Moisture content, wet basis:** Moisture content expressed as a percentage of the weight of wood as-received, i.e.:

\[
\frac{\text{weight of wet sample} - \text{weight of dry sample}}{\text{weight of wet sample}} \times 100
\]

**Monoculture:** The cultivation of a single species crop.

**Net present value:** The sum of the costs and benefits of a project or activity. Future benefits and costs are discounted to account for interest costs.

**Nitrogen fixation:** The transformation of atmospheric nitrogen into nitrogen compounds that can be used by growing plants.

**Noncondensing, controlled extraction turbine:** A turbine that bleeds part of the main steam flow at one (single extraction) or two (double extraction) points.

**Old growth:** Timber stands with the following characteristics: large mature and over-mature trees in the overstory, snags, dead and decaying logs on the ground, and a multi-layered canopy with trees of several age classes.

**Organic compounds:** Chemical compounds based on carbon chains or rings and also containing hydrogen, with or without oxygen, nitrogen, and other elements.
**Particulate:** A small, discrete mass of solid or liquid matter that remains individually dispersed in gas or liquid emissions. Particulates take the form of aerosol, dust, fume, mist, smoke, or spray. Each of these forms has different properties.

**Photosynthesis:** Process by which chlorophyll-containing cells in green plants convert incident light to chemical energy, capturing carbon dioxide in the form of carbohydrates.

**Pilot scale:** The size of a system between the small laboratory model size (bench scale) and a full-size system.

**Present value:** The worth of future receipts or costs expressed in current value. To obtain present value, an interest rate is used to discount future receipts or costs.

**Process heat:** Heat used in an industrial process rather than for space heating or other housekeeping purposes.

**Producer gas:** Fuel gas high in carbon monoxide (CO) and hydrogen (H2), produced by burning a solid fuel with insufficient air or by passing a mixture of air and steam through a burning bed of solid fuel.

**Public utility commissions:** State agencies that regulate investor-owned utilities operating in the state.

**Public Utility Regulatory Policies Act:** (PURPA) A federal law requiring a utility to buy the power produced by a qualifying facility at a price equal to that which the utility would otherwise pay if it were to build its own power plant or buy power from another source.

**Pyrolysis:** The thermal decomposition of biomass at high temperatures (greater than 400° F, or 200° C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

**Quad:** One quadrillion Btu (10^15 Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent.

**Recovery boiler:** A pulp mill boiler in which lignin and spent cooking liquor (black liquor) is burned to generate steam.

**Refractory Lining:** A lining, usually of ceramic, capable of resisting and maintaining high temperatures.

**Refuse-derived fuel:** (RDF) Fuel prepared from municipal solid waste. Noncombustible materials such as rocks, glass, and metals are removed, and the remaining combustible portion of the solid waste is chopped or shredded. RDF facilities process typically between 100 and 3,000 tons of MSW per day.
**Reserve Margin:** The amount by which the utility's total electric power capacity exceeds maximum electric demand.

**Return on investment:** (ROI) The interest rate at which the net present value of a project is zero. Multiple values are possible.

**Rotation:** Period of years between establishment of a stand of timber and the time when it is considered ready for final harvest and regeneration.

**Saturated steam:** Steam at boiling temperature for a given pressure.

**Shaft horsepower:** A measure of the actual mechanical energy per unit time delivered to a turning shaft. See also horsepower.

**Silviculture:** Theory and practice of controlling the establishment, composition, structure and growth of forests and woodlands.

**SRIC:** Short rotation intensive culture - the growing of tree crops for bioenergy or fiber, characterized by detailed site preparation, usually less than 10 years between harvests, usually fast-growing hybrid trees and intensive management (some fertilization, weed and pest control, and possibly irrigation).

**Stand:** (of trees) A tree community that possesses sufficient uniformity in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities.

**Steam turbine:** A device for converting energy of high-pressure steam (produced in a boiler) into mechanical power which can then be used to generate electricity.

**Superheated steam:** Steam which is hotter than boiling temperature for a given pressure.

**Surplus electricity:** Electricity produced by cogeneration equipment in excess of the needs of an associated factory or business.

**Sustainable:** An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

**Therm:** A unit of energy equal to 100,000 Btus (= 105.5 MJ); used primarily for natural gas.

**Thermochemical conversion:** Use of heat to chemically change substances from one state to another, e.g. to make useful energy products.

**Tipping fee:** A fee for disposal of waste.

**Ton, tonne:** One U.S. ton (short ton) = 2,000 pounds. One Imperial ton (long ton or shipping ton) = 2,240 pounds. One metric tonne (tonne) = 1,000 kilograms (2,205 pounds). One oven-dry ton
or tonne (ODT, sometimes termed bone-dry ton/tonne) is the amount of wood that weighs one ton/tonne at 0% moisture content. One green ton/tonne refers to the weight of undried (fresh) biomass material - moisture content must be specified if green weight is used as a fuel measure.

**Topping cycle:** A cogeneration system in which electric power is produced first. The reject heat from power production is then used to produce useful process heat.

**Topping and back pressure turbines:** Turbines which operate at exhaust pressure considerably higher than atmospheric (noncondensing turbines). These turbines are often multistage types with relatively high efficiency.

**Transmission:** The process of long-distance transport of electrical energy, generally accomplished by raising the electric current to high voltages.

**Traveling grate:** A type of furnace in which assembled links of grates are joined together in a perpetual belt arrangement. Fuel is fed in at one end and ash is discharged at the other.

**Turbine:** A machine for converting the heat energy in steam or high temperature gas into mechanical energy. In a turbine, a high velocity flow of steam or gas passes through successive rows of radial blades fastened to a central shaft.

**Turn down ratio:** The lowest load at which a boiler will operate efficiently as compared to the boiler's maximum design load.

**Waste streams:** Unused solid or liquid by-products of a process.

**Water-cooled vibrating grate:** A boiler grate made up of a tuyere grate surface mounted on a grid of water tubes interconnected with the boiler circulation system for positive cooling. The structure is supported by flexing plates allowing the grid and grate to move in a vibrating action. Ashes are automatically discharged.

**Watershed:** The drainage basin contributing water, organic matter, dissolved nutrients, and sediments to a stream or lake.

**Watt:** The common base unit of power in the metric system. One watt equals one joule per second, or the power developed in a circuit by a current of one ampere flowing through a potential difference of one volt. One Watt = 3.413 Btu/hr. See also kilowatt.

**Wheeling:** The process of transferring electrical energy between buyer and seller by way of an intermediate utility or utilities.

**Whole-tree harvesting:** A harvesting method in which the whole tree (above the stump) is removed.

**Yarding:** The initial movement of logs from the point of felling to a central loading area or landing.
APPENDIX B: BIOENERGY CONVERSION FACTORS
(Source: http://bioenergy.ornl.gov/papers/misc/energy_conv.html)

B.1 Weight and Volume

Some Common Units of Measure
- 1.0 U.S. ton (short ton) = 2000 pounds
- 1.0 imperial ton (long ton or shipping ton) = 2240 pounds
- 1.0 metric tonne (tonne) = 1000 kilograms = 2205 pounds
- 1.0 US gallon = 3.79 liter = 0.833 Imperial gallon
- 1.0 imperial gallon = 4.55 liter = 1.20 US gallon
- 1.0 liter = 0.264 US gallon = 0.220 imperial gallon
- 1.0 US bushel = 0.0352 m³ = 0.97 UK bushel = 56 lb, 25 kg (corn or sorghum) = 60 lb, 27 kg (wheat or soybeans) = 40 lb, 18 kg (barley)

The conversion factors between ton and thousand board feet (MBF) for hardwood and softwood residues are listed in Table B.1.

Table B.1 Residue conversion factors.

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<th>Fine</th>
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<tr>
<td>Hardwood</td>
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<td>Softwood</td>
<td>0.4005</td>
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</table>

*One ton = 2.5 cords; one ft³ = 85.0 cords (source: Hansen B. et al. 2006).

B.2 Energy Units

Quantities
- 1.0 joule (J) = one Newton applied over a distance of one meter (= 1 kg m²/s²).
- 1.0 joule = 0.239 calories (cal)
- 1.0 calorie = 4.187 J
- 1.0 gigajoule (GJ) = 10⁹ joules = 0.948 million Btu = 239 million calories = 278 kWh
- 1.0 British thermal unit (Btu) = 1055 joules (1.055 kJ)
- 1.0 Quad = One quadrillion Btu (10¹⁵ Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent (boe)
- 1000 Btu/lb = 2.33 gigajoules per tonne (GJ/t)
- 1000 Btu/US gallon = 0.279 megajoules per liter (MJ/l)

Power
- 1.0 watt = 1.0 joule/second = 3.413 Btu/hr
- 1.0 kilowatt (kW) = 3413 Btu/hr = 1.341 horsepower
• 1.0 kilowatt-hour (kWh) = 3.6 MJ = 3413 Btu
• 1.0 horsepower (hp) = 550 foot-pounds per second = 2545 Btu per hour = 745.7 watts = 0.746 kW

Energy Costs
• $1.00 per million Btu = $0.948/GJ
• $1.00/GJ = $1.055 per million Btu

Areas and Crop Yields
• 1.0 hectare = 10,000 m² (an area 100 m x 100 m, or 328 x 328 ft) = 2.47 acres
• 1.0 km² = 100 hectares = 247 acres
• 1.0 acre = 0.405 hectares
• 1.0 US ton/acre = 2.24 t/ha
• 1 metric ton/hectare = 0.446 ton/acre
• 100 g/m² = 1.0 tonne/hectare = 892 lb/acre
  o for example, a "target" bioenergy crop yield might be: 5.0 US tons/acre (10,000 lb/acre) = 11.2 tonnes/hectare (1120 g/m²)

Biomass Energy
• Cord: a stack of wood comprising 128 cubic feet (3.62 m³); standard dimensions are 4 x 4 x 8 feet, including air space and bark. One cord contains approx. 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg
  o 1.0 metric tonne wood = 1.4 cubic meters (solid wood, not stacked)
  o Energy content of wood fuel (HHV, bone dry) = 18-22 GJ/t (7,600-9,600 Btu/lb)
  o Energy content of wood fuel (air dry, 20% moisture) = about 15 GJ/t (6,400 Btu/lb)
• Energy content of agricultural residues (range due to moisture content) = 10-17 GJ/t (4,300-7,300 Btu/lb)
• Metric tonne charcoal = 30 GJ (= 12,800 Btu/lb) (but usually derived from 6-12 t air-dry wood, i.e. 90-180 GJ original energy content)
• Metric tonne ethanol = 7.94 petroleum barrels = 1262 liters
  o ethanol energy content (LHV) = 11,500 Btu/lb = 75,700 Btu/gallon = 26.7 GJ/t = 21.1 MJ/liter. HHV for ethanol = 84,000 Btu/gallon = 89 MJ/gallon = 23.4 MJ/liter
  o ethanol density (average) = 0.79 g/ml (= metric tonnes/m³)
• Metric tonne biodiesel = 37.8 GJ (33.3 - 35.7 MJ/liter)
  o biodiesel density (average) = 0.88 g/ml (= metric tonnes/m³)

Fossil Fuels
• Barrel of oil equivalent (boe) = approx. 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. "Petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 liters); about 7.2 barrels oil are equivalent to one tonne of oil (metric) = 42-45 GJ.
• Gasoline: US gallon = 115,000 Btu = 121 MJ = 32 MJ/liter (LHV). HHV = 125,000 Btu/gallon = 132 MJ/gallon = 35 MJ/liter
  o Metric tonne gasoline = 8.53 barrels = 1356 liter = 43.5 GJ/t (LHV); 47.3 GJ/t (HHV)
• gasoline density (average) = 0.73 g/ml (= metric tonnes/m³)

• **Petro-diesel** = 130,500 Btu/gallon (36.4 MJ/liter or 42.8 GJ/t)
  - petro-diesel density (average) = 0.84 g/ml (= metric tonnes/m³)

• Note that the energy content (heating value) of petroleum products per unit mass is fairly constant, but their density differs significantly – hence the energy content of a liter, gallon, etc. varies between gasoline, diesel, kerosene.

• Metric tonne **coal** = 27-30 GJ (bituminous/anthracite); 15-19 GJ (lignite/sub-bituminous)
  - (the above ranges are equivalent to 11,500-13,000 Btu/lb and 6,500-8,200 Btu/lb).
  - Note that the energy content (heating value) per unit mass varies greatly between different "ranks" of coal. "Typical" coal (rank not specified) usually means bituminous coal, the most common fuel for power plants (27 GJ/t).

• **Natural gas**: HHV = 1027 Btu/ft³ = 38.3 MJ/m³; LHV = 930 Btu/ft³ = 34.6 MJ/m³
  - Therm (used for natural gas, methane) = 100,000 Btu (= 105.5 MJ)

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**Carbon Content of Fossil Fuels and Bioenergy Feedstocks**

• **coal** (average) = 25.4 metric tonnes carbon per terajoule (TJ)
  - 1.0 metric tonne **coal** = 746 kg carbon

• **oil** (average) = 19.9 metric tonnes carbon / TJ

• 1.0 US gallon **gasoline** (0.833 Imperial gallon, 3.79 liter) = 2.42 kg carbon

• 1.0 US gallon **diesel/fuel oil** (0.833 Imperial gallon, 3.79 liter) = 2.77 kg carbon

• **natural gas (methane)** = 14.4 metric tonnes carbon / TJ

• 1.0 cubic meter **natural gas (methane)** = 0.49 kg carbon

• carbon content of **bioenergy feedstocks**: approx. 50% for woody crops or wood waste; approx. 45% for graminaceous (grass) crops or agricultural residues
## APPENDIX C: BIOMASS RESEARCH AND DEVELOPMENT DIRECTORY IN WEST VIRGINIA AND OTHER STATES

### C.1 Individuals Working in Biomass/Bioenergy

<table>
<thead>
<tr>
<th>Contact</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bailey, Brent</td>
<td>The Mountain Institute</td>
</tr>
<tr>
<td></td>
<td>1707 L Street NW, Suite 1030,</td>
</tr>
<tr>
<td></td>
<td>Washington, DC 20036</td>
</tr>
<tr>
<td></td>
<td>304-685-3481</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:bbailey@mountain.org">bbailey@mountain.org</a></td>
</tr>
<tr>
<td>Bajura, Richard</td>
<td>WVU NRCCE</td>
</tr>
<tr>
<td></td>
<td>P.O. Box 6064 Evansdale Drive</td>
</tr>
<tr>
<td></td>
<td>WVU Morgantown, WV 26506</td>
</tr>
<tr>
<td></td>
<td>304-293-2867 x 5401</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:richard.bajura@wvu.edu">richard.bajura@wvu.edu</a></td>
</tr>
<tr>
<td>Bakanas, Carol</td>
<td>WVDEP/Solid Waste</td>
</tr>
<tr>
<td></td>
<td>601 57th Street.</td>
</tr>
<tr>
<td></td>
<td>Charleston, WV 25304</td>
</tr>
<tr>
<td></td>
<td>304-926-0499 x 1316</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:cbakanas@wvdep.org">cbakanas@wvdep.org</a></td>
</tr>
<tr>
<td>Balasko, John</td>
<td>WVU Plant &amp; Soil Sci.</td>
</tr>
<tr>
<td></td>
<td>1082 Ag. Sci. Bldg. WVU PO Box 6108</td>
</tr>
<tr>
<td></td>
<td>Morgantown, WV 26506-6108</td>
</tr>
<tr>
<td></td>
<td>304-293-6256</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:jbalasko@wvu.edu">jbalasko@wvu.edu</a></td>
</tr>
<tr>
<td>Barrett, Joseph</td>
<td>DOE, Philadelphia</td>
</tr>
<tr>
<td></td>
<td>U.S. Department of Energy 1000 Independence Ave., SW</td>
</tr>
<tr>
<td></td>
<td>Washington, DC 20585</td>
</tr>
<tr>
<td></td>
<td>215-656-6957</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:joseph.barrett@ee.doe.gov">joseph.barrett@ee.doe.gov</a></td>
</tr>
<tr>
<td>Baskin, Kathryn</td>
<td>Southeastern Regional Biomass Energy Program (SERBEP)</td>
</tr>
<tr>
<td>Diehl, Cain</td>
<td>Southern States Energy Board 6325 Amherst Court</td>
</tr>
<tr>
<td></td>
<td>Norcross, GA 30092</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.serbep.org">www.serbep.org</a></td>
</tr>
<tr>
<td></td>
<td><a href="mailto:diehl@sseb.org">diehl@sseb.org</a></td>
</tr>
<tr>
<td></td>
<td><a href="mailto:baskin@sseb.org">baskin@sseb.org</a></td>
</tr>
<tr>
<td>Bassage, Dave</td>
<td>DEP – Innovation</td>
</tr>
<tr>
<td></td>
<td>P.O. Box 6064 Evansdale Drive WVU</td>
</tr>
<tr>
<td></td>
<td>Morgantown, WV 26506</td>
</tr>
</tbody>
</table>
Bingaman, David  
PA Department of Agriculture  
Pennsylvania Department of Agriculture 2301 North Cameron Street  
Harrisburg, PA 17110  
(717)-772-5208  
dbingaman@state.pa.us

Bragg, Kelly  
West Virginia Clean Cities Coalition  
West Virginia Development Office Building 6 Room 645  
Charleston, WV 25305  
304-558-0350  
kbragg@wvdo.org

Challman, Don  
CAER Associate Director  
UK Center for Applied Energy Research, 2540 Research Park Drive,  
Lexington, KY 40511-8479 USA  
859-257-0222  
challman@caer.uky.edu

Cooke, Dick  
WV SWMB  
601, 57th Street SE  
Charleston, WV 25304  
304-926-0448  
dcooke@wvswmb.org

Cullen, Kathleen  
WVU Nat. Res. Center for Coal & Energy  
P.O. Box 6064 Evansdale Drive WVU  
Morgantown, WV 26506  
304-293-2867x5426  
Kathleen.Cullen@mail.wvu.edu

Dawson-Andoh, Benjamin  
WVU WDSC  
206G Percival Hall PO Box 6125  
Morgantown, WV 26506  
304-293-3825x2487  
bdawsona@mail.wvu.edu

Davies, John  
Kentucky Office of Energy Policy  
500 Mero Street, 12th Floor, Capital Plaza Tower  
Frankfort, KY 40601  
502-564-7484  
John.Davies@ky.gov

Ebron, Al  
WVU National Alternative Fuels Training Consortium
Esposito, Pat
WV energy task force
Capitol Complex Building 6 Room 553 1900 Kanawha Blvd E.
WV 25305-0311
pesposito@augustasystems.com

Feliachi, Ali
WVU Comp. Sci. & Electrical Eng.
Engineering Sciences Building PO Box 6109
Morgantown, WV 26506
304-293-0405x2529
alfeliachi@mail.wvu.edu

Felton, Eugene
WVU Animal Sci.
G038 Agricultural Sciences Building PO Box 6108
Morgantown, WV 26506-6108
304-293-2631
gene.felton@mail.wvu.edu

Flenner, Bill
WVPSC
201 Brooks Street
Charleston, WV 25301
304-340-0496
bflenner@psc.state.wv.us

Geertsema, Ari
CAER Director
UK Center for Applied Energy Research, 2540 Research Park Drive,
Lexington, KY 40511-8479 USA
859-257-0306
ari@caer.uky.edu

Gilliam, Frank
Biological Sciences
One John Marshall Drive
Huntington, WV 25755
304-696-3636
gilliam@marshall.edu

Goff, Tony
WVU Div. of Forestry
205H Percival Hall PO Box 6125
Morgantown, WV 26506
304-293-2941 x2429
gofftony@hotmail.com

Grushecky, Shawn
Appalachian Hardwood Center
Goodge, Anne
The Ohio Biomass Energy Program
Public Utilities Commission of Ohio 180 East Broad Street
Columbus, OH 43215-3793
614-644-7857
Anne.goodge@puc.state.oh.us

Hall, Dennis
Ohio State University
2001 FYFFE COURT
Columbus, OH 43210
614-292-4188
hall.16@osu.edu

Hansen, Evan
Downstream Strategies
Downstream Strategies, LLC 219 Wall Street
Morgantown, WV 26505
304-291-8205
ehansen@downstreamstrategies.com

Hassler, Curt
Balken-Tier Consult.
1143 Aarons Creek Rd,
Morgantown, WV 26508-9558
304-282-5417
curth@mail.wvnet.edu

Herholdt, Jeff
WVDO/EEP
West Virginia Development Office Building 6 Room 645
Charleston, WV 25305
304-558-2234
jherholdt@wvdo.org

Irwin, Carl
WVU NRCCE
P.O. Box 6064 Evansdale Drive WVU
Morgantown, WV 26506
304-293-2867x5403
carl.irwin@mail.wvu.edu / cirwin2@wvu.edu

Karmis, Michael
VEPT
Virginia Center for Coal and Energy Research (0411)
Virginia Tech Blacksburg, VA 24061
540-231-7057
mkarmis@vt.edu
Klinke, David
WVU Chem. Eng.
Department of Chemical Engineering PO Box 6102
Morgantown, WV 26506
304-293-2111x2435
david.klinke@mail.wvu.edu

Kotcon, James
WVU Plant & Soil Sci.
1090 Agriculture Science Building PO Box 6108
Morgantown, WV 26506
304-293-8822
jkotcon@wvu.edu

Li, Michael
Renewable Energy
Maryland Energy Administration 1623 Forest Drive, Suite 300
Annapolis MD 21403
410-260-7183
mli@energy.state.md.us

Logan, Bruce
PSU Dept. of Information, Prof. Env. Eng.
Penn State Institutes of the Environment, Land and Water Research Bldg.,
University Park, PA 16802
814-863-7908
blogan@psu.edu

Maryland Energy Administration
http://www.energy.state.md.us/about/staff.htm
Maryland Energy Administration 1623 Forest Drive, Suite 300
Annapolis MD 21403
410-260-7655
meainfo@energy.state.md.us

McNeel, Joe
WVU Div. of For.
322 Percival Hall PO Box 6125
Morgantown, WV 26506
304-293-2941x2471
jmcneel@wvu.edu

Means, Ken
Engineering Science Building PO Box 6106
Morgantown, WV, 26506
304-293-3111x2308
kmeans@mail.wvu.edu

Myers, Stephen
BioProducts Innovation Center, Director
152 Howlett Hall 2001 Fyffe Court Ohio State University
Columbus, OH 43210
614-292-1399
myers.603@osu.edu
Osborn, Larry  
WVU Grant Res. Assoc.  
205A Percival Hall PO Box 6125  
Morgantown, WV 26506  
304-293-2941x2455  
losborn2@wvu.edu

Pahl, Tim  
Balken-Tier Consult.  
2337 Stewartstown Rd  
Morgantown, WV 26508-1462

Ray, Chuck  
PSU Asst. Prof. Wood Operations  
301A Forest Resources Lab  
University Park, PA 16802  
814-865-0679  
cdr14@psu.edu

Rayburn, Ed  
WVU Ag & Nat. Res.  
1078Ag Sci Bldg PO Box 6108  
Morgantown, WV, 26506  
304-293-6131  
erayburn@wvu.edu

Rice, Chris  
Biomass Emergency Management  
Maryland Energy Administration 1623 Forest Drive, Suite 300  
Annapolis MD 21403  
410-260-7207  
crice@energy.state.md.us

Richard, Tom  
PSU Ag. And Biological Eng.  
University Park, PA 16802-1909  
814-865-3722  
trichard@psu.edu

Risch, Christie  
Marshall U./CBER  
One John Marshall Drive -  
Huntington, WV 25755  
304-696-6251  
christine.risch@marshall.edu

Roth, Greg  
PSU Agronomy/Extension  
407 AG SCI & IND BLDG  
UNIVERSITY PARK, PA 16802  
814-863-7043  
gwn@psu.edu
Scott, Bob
Office of Econ. Opportunity
950 Kanawha Boulevard East, 3rd Floor
Charleston, WV 25301
304-558-8860x16
bscott@oeo.state.wv.us

Sherrick, Joe
DEP
The Pennsylvania Department of Agriculture 2301 North Cameron Street
Harrisburg, PA 17110
(717)-772-8944
josherrick@state.pa.us

Slahor, Jeff
WVU Res. Inst.
218 Percival Hall PO Box 6125
Morgantown, WV, 26506
304-293-2941 x2461
jslahor@wvu.edu

Stiller, Alfred
WVU Chem. Eng.
413 Eng Sci Bd PO Box 6102
Morgantown, WV, 26506
304-293-2111x2408
alfred.stiller@mail.wvu.edu

Wang, Jingxin
WVU Div. of For.
206B Percival Hall PO Box 6125
Morgantown, WV, 26506-6125
304-293-2941 x2481
jxwang@wvu.edu

Webber, Dianna
The Ohio Biomass Energy Program
Public Utilities Commission of Ohio 180 East Broad Street
Columbus, OH 43215-3793
614-466-2871

Young, Ray
WVU Chem. Eng.
441 Eng Sci Bd
PO Box 6102
304 293-2111 x2419
ryan@mail.wvu.edu

Zhang, Wu
WVU Chem. Eng.
G53 Eng Sci Bd PO Box 6102
Morgantown, WV, 26506
304-293-2111x2422
wu.zhang@mail.wvu.edu
### C.2 Companies, Agencies, and National Labs

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<th>Name</th>
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<tr>
<td>Allegheny Wood Products</td>
<td>Kingwood Ahn 1415, Kingwood, WV 26537</td>
<td>(304) 329-3895</td>
</tr>
<tr>
<td>Appalachian Custom Dry Kilns, LLC</td>
<td>Holden, WV 25625</td>
<td>304-239-3002/3011</td>
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<tr>
<td>Appalachian Forest Products</td>
<td>RR 33, Buckhannon, WV 26201</td>
<td>304-472-2996</td>
</tr>
<tr>
<td></td>
<td>901 D Street, SW, Suite 100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Washington, DC 20024</td>
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</tr>
<tr>
<td></td>
<td>847-381-6320</td>
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</tr>
<tr>
<td></td>
<td><a href="mailto:beraorg2@excite.com">beraorg2@excite.com</a></td>
<td></td>
</tr>
<tr>
<td>Columbia Forest Products</td>
<td>271 Flat Top Road, Shady Spring, WV 25918</td>
<td>(304) 763-0633</td>
</tr>
<tr>
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<td><a href="http://www.columbiaforestproducts.com/">http://www.columbiaforestproducts.com/</a></td>
</tr>
<tr>
<td>Keeler, Craig</td>
<td>Spencer Veneer LLC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>270 Industrial Road, Spencer, WV 25276</td>
<td>304-927-5815</td>
</tr>
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<td><a href="mailto:gwvspencer@wirefire.com">gwvspencer@wirefire.com</a></td>
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<tr>
<td>Cranberry Lumber Company</td>
<td>Macfarlan, WV 26148</td>
<td>304-477-3037</td>
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<tr>
<td>Dallison Lumber Inc</td>
<td>Jacksonburg, WV 26377</td>
<td>304-889-3232</td>
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<tr>
<td>Eastern Hardwoods Inc</td>
<td>Garden Ground Station, Mount Hope, WV 25880</td>
<td>304-877-3541</td>
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<td>Frazee, Rodney</td>
<td>TAZ Hardwoods Timber Co. Inc.</td>
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<tr>
<td></td>
<td>Castell Road, Bruceton Mills, WV 26525</td>
<td>304-379-4225</td>
</tr>
<tr>
<td>Company</td>
<td>Address</td>
<td>Phone</td>
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<tr>
<td>Georgia-Pacific Corporation</td>
<td>79 North Pax Avenue, Mount Hope, WV 25880</td>
<td>304-846-2504</td>
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<tr>
<td>Greenbrier Forest Products Inc</td>
<td>Smoot Dawson Road, Rupert, WV 25984</td>
<td>304-392-6453</td>
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<td><a href="http://www.greenbrierwv.com">http://www.greenbrierwv.com</a></td>
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<tr>
<td>High Mountain Timber LLC</td>
<td>RR 219, Dailey, WV 26259</td>
<td>304-338-4515</td>
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<td>Highland Forest Products</td>
<td>1700 Airport Road, Sutton, WV 26601</td>
<td>304-765-7177</td>
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<td>Huskie Lumber Co Inc</td>
<td>RR 7, Wana, WV 26590</td>
<td>304-662-6275</td>
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<tr>
<td>Interdevelopment, Inc.</td>
<td><a href="http://www.interdevelopment.com">www.interdevelopment.com</a></td>
<td>202-508-1459</td>
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<tr>
<td>Parsons, Jeff</td>
<td>Oak Pointe Farms</td>
<td>304-727-2515</td>
</tr>
<tr>
<td></td>
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<td><a href="mailto:jparsons@timbermark.com">jparsons@timbermark.com</a></td>
</tr>
<tr>
<td>Pellet Fuels Institute</td>
<td>1901 North Moore Street Suite 600</td>
<td>703-522-6778</td>
</tr>
<tr>
<td>Sayre, Kenny</td>
<td>Jim C. Hamer Company</td>
<td>304-637-2522</td>
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<tr>
<td>Kupfer Brothers Logging Sawmill</td>
<td>RR 250, Cameron, WV 26033</td>
<td>304-686-2783</td>
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<td>Judy, Levi</td>
<td>Coastal Lumber Company</td>
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Miller Pallet & Lumber CO  
Creston, WV 26141  
354-6256

Mullican B A Lumber  
Ronceverte, WV 24970  
304-647-3071

North Fork Forest Products Inc  
Ellenboro, WV 26346  
304-869-3166

Plum Creek Timber CO  
RR 219, Lewisburg, WV 24901  
304-645-1542

Phares, Robert  
Hi-Tech Dry Kiln Company, LLC  
Industrial Park, Belington, WV 26250  
304-823-2355

Renewable Fuels Association  
One Massachusetts Avenue, NW - Suite 820 -  
Washington, DC 20001  
202-289-3835  
http://www.ethanolrfa.org/

Sheets, Darrell  
General Sales Manager  
96 MacCorkle Avenue S.W. - P.O. Box 18370 -  
South Charleston, WV 25303  
304-746-3160  
www.gilcolumber.com

Sun Lumber Co  
26 Main Avenue, Weston, WV 26452  
304-269-1000

Switch  
Switch 4202 Conally Street Suite 202  
Annandale, VA 22003  
703-941-284  
http://www.switchonenergy.com

Talbott Lumber Co Inc  
Industrial Park, Belington, WV 26250  
304-823-2200

Lambert, Travis  
BPBCORP.COM  
3424 Parkersburg Road, Reedy, WV 25270  
304-927-0232  
Bpbcorp@Bpbcorp.com

TRUS Joist Macmillan  
Madison, WV 25130  
304-369-3646
Barriner, Victor  
Coastal Lumber Company  
PO Box 829 1772 Trueblood Road  
Weldon, NC  27890  
(800) 735-2727  
clicinfo@coastallumber.com

Wagner Forest Management  
513 Cherry Street, Bluefield, WV 24701  
304-324-7557

Western Pocahontas Properties  
1035 3rd Avenue, Huntington, WV 25701  
304-522-5757

Westvaco Corporation Timberlands  
DIV  
525 Center Street, Elkins, WV 26241  
304-636-7760

Bender, Bob Chiptec  
http://www.chiptec.com/  
48 Helen Avenue  
South Burlington VT 05403  
800-244-4146  
BobBender@Chiptec.com

Community Power Corporation  
www.gopc.com  
8110 Shaffer Parkway  
Suite 120 Littleton, CO 80127  
(303) 933-3135  
Art Lilley artsolar@aol.com  
Robb Walt rwalt@gopc.com

NREL  
Biomass  
National Renewable Energy Laboratory 1617 Cole Blvd.  
Golden, CO 80401-3393  
(303) 384-6826  
http://www.nrel.gov/

Benson, Steve  
Energy and Environmental Research Center  
(701) 777-5177  
sbenson@undeerc.org

BCS  
Biomass Combustion Systems  
67 Millbrook Street, Suite 505,  
Worcester, MA 01606  
(508) 798-5970  
http://www.biomasscombustion.com/index.html
Blue Sun Biodiesel

http://gobluesun.com/
1400 W. 122nd Ave. Suite 110
Westminster, CO 80234
303-865-7700
Email: info@gobluesun.com

Continental Biomass Industries Inc.

Continental Biomass Industries, Inc. 22 Whittier Street
Newton, NH 03858
(603)-382-0556
info@cbi-inc.com

Roosa, Steve  Delta Dynamics

http://www.deltadynamicsenergy.com/contact.html
1420 Eighteenth Street
Denver, CO 80202
(303)-298-7241

Electric Technologies Co.
860-654-1699

Forest Energy Corporation
928-537-1647

Forest Products Laboratory
www.fpl.fs.fed.us
One Gifford Pinchot Dr.
Madison, WI 53726
608 231-9200

General Biomass Company
www.generalbiomass.com
General Biomass Company 2859 Central Street, #134
Evanston, IL 60201
847-433-4323
dgibbs@generalbiomass.com

GenPower
1040 Great Plain Avenue
Needham, MA 02492
781 444-9980
www.genpower.net

Industrial Biomass, Inc.
Industrial Wood Products
P.O. Box 22
Clermont, IA 52135
563-423-1800

Profab Industries, Inc.
www.profab.org
PO Box 112 Arborg,
MB Canada R0C 0A0
204-364-2211/888-933-4440

Pure Vision Technology, Inc.
www.purevisiontechnology.com
511 McKinley Avenue
Ft. Lupton, CO 80621
303-857-4530

SeQuential Biofuels, LLC
www.sqbiofuels.com
7326 N. Chicago Ave.
Portland, Oregon 97203
503-978-3210

Technology Ventures Corporation
www.techventures.org
1155 University Blvd. SE
Albuquerque, NM 87106

VA DEQ
629 East Main Street P.O. Box 10009
Richmond, VA 23240-0009
804-698-4000

WV Development Office
www.wvdo.org
Energy Efficiency Program
Capitol Complex, Building 6, Room 645
Charleston, WV 25305
304-558-0350