# Size, Moisture Content, and British Thermal Unit Value of Processed In-Woods Residues: Five Case Studies

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**Abstract**

With the increased emphasis in the utilization of biomass for energy, the interest in wood as an energy resource has moved from just mill residues to include in-woods residues. This study looked at five examples of in-woods biomass collection: two chipping operations and three grinding operations. Samples were taken from three truckloads at each operation and analyzed for particle size distribution, moisture content, British thermal unit value per ovendry pound, and ash content. The average characteristics of the processed residue were 87 percent moisture content, 7,945 Btu/lb oven dried, and 3.1 percent ash content.

In the 1970s with the OPEC oil embargo, an energy crisis resulted in the United States. The wood using industry in the United States was encouraged to start using mill residues as an energy source. Some in-woods harvesting of fuel wood was started but discontinued when the price of oil dropped. In the 1980s, the price of oil climbed again, and loggers were encouraged to buy fuel wood harvesting equipment. McMinn and Clark (1988) concluded that residuals could be harvested and used for fuel. Because of the equipment available at that time, they recommended that the residuals be harvested while standing and before the primary harvest. Saucier and Phillips (1985) concluded that logging residues and cull trees were most economically harvested by whole-tree chipping in the woods and transporting the chips to the combustion facility. But the price of oil dropped again, and some loggers went bankrupt because there was no demand for fuel wood and they still had to pay for the equipment.

Since then, additional equipment has become available for harvesting this in-woods material, such as horizontal grinders. Also, Patterson et al. (2008), with four case studies, demonstrated the feasibility of using slash bundlers to compact the residue into ‘‘loglike’’ bundles that can be easily forwarded to the landing and loaded onto trucks.

Price fluctuations in the oil market, combined with greatly reduced quantities of mill residues brought on by reduced lumber demand, have renewed interest in energy wood and wood as an advanced biofuel feedstock. Companies are encouraging loggers to purchase in-woods equipment to process logging residues and growing stock for fuel wood. Some loggers are reluctant to do so without long-term contracts that will guarantee them the money to pay for their investment in equipment. Companies are reluctant to commit because they do not know the characteristics of the materials being delivered and how these materials will affect their financial viability in the long run (personal communication).

One of the main problems in using wood residues for energy is the moisture content. This includes the moisture in the residues at harvest as well as moisture pickup in storage. Rogers (1981) found that after harvest, treetops lost moisture when allowed to remain at the harvest site for 12 weeks in the winter. He concluded that the net heating value increased 68.9 percent for loblolly pine tops, 16.9 percent for sweetgum tops, and 9.0 percent for white oak. White and DeLuca (1978) and Saucier and Phillips (1985) found that flat piles allowed rain to percolate down through the pile, causing the moisture content of the interior of the pile to

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increase, whereas conical piles tended to ''shed'' the water, causing the moisture content of the interior to decrease. The moisture content of the conical piles did not fluctuate with changes in the weather. Patterson et al. (2010) found that the moisture content of slash bundles stored outside did fluctuate with weather changes.

Clark and Taras (1976) analyzed the components of southern pine trees. They found that bark weight was 15 to 19 percent of the total weight of aboveground biomass for small trees and 10 to 12 percent for larger trees. Needles made up 6 percent of the total weight for smaller trees and 3 percent for larger trees. When analyzing just the branches, bark weight was 20 percent of the total weight of the branches.

Patterson and Zinn (1990) compiled the results of many studies on wood as an energy resource. Most of the reviewed articles agreed with 8,600 Btu per ovendry pound as the generic value for wood, although the values from various investigators ranged from 8,600 to 9,150 Btu per pound for softwoods and 6,840 to 8,180 Btu per pound for hardwoods. The reported British thermal unit (Btu) per ovendry pound values for bark ranged from 8,800 to 10,800 for softwoods and 7,400 to 9,800 for hardwoods. The average of those studies for percent ash content was 0.4 percent for wood and 1.8 percent for bark. This would indicate that bark produces four times more ash per pound than wood. If wood and bark were processed together, then the ash content would be a weighted average of the two. Funck and Hoag (1985) studied western softwoods and found that bark ash content increased with an increase in tree diameter.

During the energy crises of the 1970s and 1980s, the research effort was targeted toward mill residues. At most of the mills, the residue types (bark, sawdust, chips, etc.) were usually segregated and easily studied. Today, mill residues are no longer the ''low-hanging fruit'' but are being utilized for in-house energy or raw material for another product. Therefore, the focus today is turning toward utilizing in-woods residues.

In-wood residues are the material not taken to the mills in the past. These include limbs and tops of harvested trees, cull trees, and trees of an undesirable species, such as hardwoods in a pine plantation. In-wood residues contain a higher percentage of bark, and foliage is also included. Therefore, in-wood residues are not the same as mill residues, and their properties need to be determined.

The goal of this study was to obtain a ''snapshot picture'' of five operations to obtain knowledge of the general characteristics of processed in-wood residues. Funding and time limitations to this study did not permit evaluation of all possible combinations of machines and harvest sites. Reviewing past literature, the energy content of wood has been referred to as fuel value, heating value, high heating value, and gross heating value. The authors have decided to use the units Btu's per ovendry pound throughout this article and allow the readers to assign whatever titles they desire.

## Collection Procedures

The study team visited five operations in southeast Arkansas. Two of the operations were using chippers (Case Studies 1 and 2), and three were using horizontal grinders (Case Studies 3, 4, and 5). Chippers blow the chips into the back of a closed trailer van that has small screened windows to allow the air pressure to escape. The length of the van is sufficient so that the air pressure drops and the fines fall from the stream while the coarse material goes to the front wall of the van. As the chip pile face moves toward the rear of the van, the particle sizes become more mixed, and at the back there is no size separation. To obtain samples with no size separation, samples were collected from the back of the vans after they pulled away from the chipper.

Grinders transport the material with conveyors; therefore, the vans servicing them have open tops. The driver positions the van so that the conveyor deposits the material at the front and moves the van forward as needed to fill the van. After pulling away from the grinder, the driver climbs a ladder at the front of the van and walks to the back and starts spreading his tarp over the top of the van as required by law. The study team had the driver collect a sample from the middle of the load prior to spreading his tarp.

One sample was taken from each of three trucks at each study site. Each sample filled a 5-gallon plastic bucket, and a lid was used to close the bucket immediately. A marker was used to label the bucket as to operator, date, and truck number, and the bucket was transported to the laboratory.

At the laboratory, two samples (each about 1.3 gal) were taken from each 5-gallon bucket. Each sample was placed on the top tray of a chip classifier (purchased from Testing Machines Inc.). The chip classifier had seven trays with different diameter round holes, and starting at the bottom, they were pan, ⅛ inch, ¼ inch, ½ inch, ⅞ inch, 1¼ inches, and 1¾ inches. The weight of each tray was known. The chip classifier oscillated for 5 minutes for each sample.

To determine size distribution, each tray was weighed to determine the amount of material that did not pass through that size hole. The material was then put in one of two types of metal pans (normally used for home cooking) depending on amount and particle size: 5 by 9-inch loaf pan or 9 by 12-inch cake pan. The pan and material were weighed and placed in an oven at 103°C for 48 hours to oven dry the material. Each pan was reweighed, and the weight of the pan was subtracted from each weighing to determine material weight. These values were used to calculate the percent moisture content on a dry basis. The dried material was placed in a plastic storage bag and taken to the cutting mill. The mill ground the material until it passed through a 2-mm screen. The material was placed back into the storage bag to store for further analysis.

An E2K oxygen bomb calorimeter was used to determine the Btu's per pound value and ash content of the samples. The calorimeter processed five samples of the ground material in each storage bag. The calorimeter required approximately half a gram (weighed to the nearest 0.0001 g) of woody material for each test. The sample weight and other pertinent information were entered into the calorimeter's computer. After firing, the calorimeter calculated and displayed the Btu value per pound. The material was burned in a crucible of known weight, and after firing the crucible was reweighed. The difference in weight was the ash content and it was divided by the sample weight and multiplied by 100 for determining the five ash values.

An unsorted control sample was taken from each bucket with a loaf pan (~2 lb) to determine an average value for the bucket. This pan of material was dried and ground in the same manner. Ten tests were conducted with the calorimeter on this material.

With five study sites, three bucket samples per site, two size samples per bucket, seven sizes per sample, and five calorimeter tests per size sample, the resulting number of calorimeter tests was 1,050. There were 10 additional tests for each of 15 loaf pan samples, or 150 more calorimeter tests, for a total of 1,200 calorimeter tests for the study.

The mean values for Btu's per pound and percent ash were analyzed by particle size using Tukey's Studentized Range Test with an alpha of 0.05.

## Case Study Analysis

### Case Study 1

A Morbark 23 chipper was used during February to chip whole trees at a fifth-row thinning operation of an 8-year-old loblolly pine plantation. The material (resembling normal chips except for the presence of bark and pine needles) was sold for fuel. The operator would vigorously shake the trees before introducing them to the chipper to remove as much soil as possible, and still the knives had to be changed after 9 to 12 truckloads. When the two skidders and one felling machine could keep the chipper supplied with trees, it would take 14 minutes to fill a truck.

The average values from the three loaf pan samples were moisture content, 121.5 percent; Btu's per ovendry pound, 8,145; and ash content, 1.4 percent. The values by particle size from the chip classifier samples are shown in Table 1.

### Case Study 2

Conehead 585 chippers are smaller and less expensive than most production chippers. The one in this case study was being used during April to harvest residues (tops and limbs) about a month after a pulpwood thinning operation of a young loblolly pine plantation. The chips appeared to be similar to the whole-tree chipper output, except there seemed to be more fines. The operator stated that they could get four truckloads before changing new knives and two before changing resharpened knives. Their production was slowed by the lack of available trucks. Many times their loaded trucks would have to wait in a long line to get into the energy facility. While waiting for the trucks to come back to the landing, the chipper would have to be shut down.

The average values from the three loaf pan samples were moisture content, 71.6 percent; Btu's per ovendry pound, 8,371; and ash content, 1.3 percent. The values by particle size from the chip classifier samples are shown in Table 2.

*Table 1.—Mean values of percentage of sample weight, percent moisture content (MC), British thermal unit value per ovendry pound, and percent ash content by particle size of whole-tree chips from a thinning operation of an 8-year-old loblolly pine plantation.*[a]

| Size (in.) | % of wt | % MC (dry basis) | Btu/lb | % ash |
|---|---|---|---|---|
| Pan | 3.0 | 84.8 | 8,211 A | 3.6 A |
| >⅛ | 6.8 | 104.8 | 8,236 A | 1.3 B |
| >¼ | 21.8 | 118.9 | 8,181 A | 0.8 B |
| >½ | 32.4 | 129.4 | 8,147 A | 1.0 B |
| >⅞ | 24.2 | 128.9 | 8,176 A | 0.9 B |
| >1¼ | 7.5 | 110.4 | 8,216 A | 1.0 B |
| >1¾ | 4.0 | 111.1 | 8,027 B | 0.7 B |
| Average | NA | 121.4 | 8,145 | 1.0 |
| Loaf pan | NA | 121.5 | 8,145 | 1.4 |

[a] Within a column, values followed by the same letter are not significantly different. NA = not applicable.

*Table 2.—Mean values of percentage of sample weight, percent moisture content (MC), British thermal unit value per ovendry pound, and percent ash content by particle size of chips from limbs and tops processed 1 month after a thinning operation of a young loblolly pine plantation.*[a]

| Size (in.) | % of wt | % MC (dry basis) | Btu/lb | % ash |
|---|---|---|---|---|
| Pan | 7.0 | 74.1 | 8,328 A | 4.3 A |
| >⅛ | 18.0 | 83.1 | 8,415 A | 2.0 B |
| >¼ | 22.8 | 66.4 | 8,303 B | 1.1 C |
| >½ | 24.5 | 52.4 | 8,243 B | 0.9 C |
| >⅞ | 11.0 | 57.3 | 8,157 C | 0.9 C |
| >1¼ | 7.7 | 63.3 | 8,147 C | 1.0 C |
| >1¾ | 8.2 | 63.3 | 8,001 D | 0.9 C |
| Average | NA | 64.5 | 8,191 | 1.4 |
| Loaf pan | NA | 71.6 | 8,371 | 1.3 |

[a] Within a column, values followed by the same letter are not significantly different. NA = not applicable.

### Case Study 3

A Peterson 6700B grinder was used during April to harvest residues (tops, limbs, and cull trees) from a clear-cut site from which mature pine trees were harvested approximately 1 year before. Much of the pine residue was ground to a material resembling potting soil, while the hardwood (oak and sweetgum) residues slowed the grinders down and came out in long strands. The operator stated that the hammers had to be changed about every 50 truckloads.

The average values from the three loaf pan samples were moisture content, 62.6 percent; Btu's per ovendry pound, 7,713; and ash content, 7.2 percent. The values by particle size from the chip classifier samples are shown in Table 3.

### Case Study 4

A Peterson 2400B grinder was being used during March to harvest residues from a pine clear-cut site from which the trees were harvested approximately 1 year before. Prior to this operation, it was used to harvest young pine trees in a precommercial harvest. The operator stated that the hammers had to be changed about every 50 truckloads.

The average values from the three loaf pan samples were moisture content, 47.8 percent; Btu's per ovendry pound, 7,870; and ash content, 1.4 percent. The values by particle size from the chip classifier samples are shown in Table 4.

*Table 3.—Mean values of percentage of sample weight, percent moisture content (MC), British thermal unit value per ovendry pound, and percent ash content by particle size of residues processed by a large horizontal grinder 1 year after a clear-cut harvest of a mature loblolly pine plantation.*[a]

| Size (in.) | % of wt | % MC (dry basis) | Btu/lb | % ash |
|---|---|---|---|---|
| Pan | 11.5 | 69.2 | 7,200 B | 11.7 A |
| >⅛ | 13.5 | 68.4 | 7,771 A | 2.6 B |
| >¼ | 22.5 | 62.8 | 7,829 A | 1.4 B |
| >½ | 22.5 | 59.6 | 7,858 A | 1.2 B |
| >⅞ | 15.2 | 54.7 | 7,882 A | 0.9 B |
| >1¼ | 7.7 | 55.7 | 7,821 A | 0.9 B |
| >1¾ | 7.2 | 51.0 | 7,883 A | 0.9 B |
| Average | NA | 61.0 | 7,775 | 2.6 |
| Loaf pan | NA | 62.6 | 7,713 | 7.2 |

[a] Within a column, values followed by the same letter are not significantly different. NA = not applicable.

*Table 4.—Mean values of percentage of sample weight, percent moisture content (MC), British thermal unit value per ovendry pound, and percent ash content by particle size of residues processed by a small horizontal grinder 1 year after a clear-cut harvest of a mature loblolly pine plantation.*[a]

| Size (in.) | % of wt | % MC (dry basis) | Btu/lb | % ash |
|---|---|---|---|---|
| Pan | 7.6 | 58.3 | 6,404 C | 24.9 A |
| >⅛ | 7.8 | 51.1 | 7,684 B | 4.2 B |
| >¼ | 12.6 | 46.8 | 7,726 BA | 2.9 C |
| >½ | 16.4 | 45.7 | 7,835 BA | 1.4 D |
| >⅞ | 13.8 | 49.1 | 7,827 A | 1.2 D |
| >1¼ | 11.2 | 40.3 | 7,890 A | 0.8 D |
| >1¾ | 30.6 | 37.1 | 7,872 A | 0.7 D |
| AverageNA | 44.3 | 7,717 | 3.3 | |
| Loaf pan | NA | 47.8 | 7,870 | 1.4 |

[a] Within a column, values followed by the same letter are not significantly different. NA = not applicable.

## Case Study 5

A Vermeer 6000 grinder was used during November to harvest residues from a loblolly pine second thinning site from which the trees were harvested less than 1 year before this operation. The operator stated that the hammers had to be changed about every 30 truckloads. The site was wet because of an extended period of rain prior to this harvest.

The average values from the three loaf pan samples were moisture content, 144.3 percent; Btu's per ovendry pound, 8,460; and ash content, 5.3 percent. The values by particle size from the chip classifier samples are shown in Table 5.

## Discussion

The values in each table are averages. The size distribution and moisture content values are the averages of six data points. The Btu values and ash content are the averages of the results of 30 calorimeter tests.

Each study was an independent observation of an independent operation. Therefore, no statistical inferences can be made across studies, but casual observations can be made.

As mentioned previously, wood has an average ash content of 0.4 percent, while bark has an average ash content of 1.8 percent (Patterson and Zinn 1990). In-wood residues and whole-tree chips have a combination of wood and bark; therefore, one would expect weighted average ash content. This appears to be the case with the larger particle sizes of all five case studies.

All the material was dragged on the ground at some point and picked up dirt and possibly other extraneous material. It appears that the chip classifier shook most of the noncombustible material to the bottom trays. Large amounts of visible sandlike material were found in the bottom of the crucibles after samples showing high ash content were burned.

As previously stated, softwoods have a higher average Btu per pound value than hardwoods, and bark has a higher average Btu per pound value than wood (Patterson and Zinn 1990). Case Studies 1, 2, and 5 involved pine plantation thinning operations; therefore, no or very little hardwood material was present in the samples. Case Studies 3 and 4 were mature pine plantation clear-cuts in which hardwoods such as oak and sweetgum invaded prior to harvest. This would explain why the Btu per pound values for Case Studies 1, 2, and 5 are higher than those of Case Studies 3 and 4.

In comparing the chipping operations (Case Studies 1 and 2), one would expect a consistent chip size or a close distribution. This appears true for Case Study 1 since its size distribution appears to be a normal distribution around the ½-inch size (Table 1). In Case Study 2, the size distribution appears flat and skewed toward the fines (Table 2). This difference could be due to the differences in machines used. More likely, though, it was due to the material being processed. In Case Study 1, the operation was chipping whole trees, and in Case Study 2, limbs and tops only were being chipped. With the limbs and tops, the needles, twigs, and bark, which would result in fines, are a higher percentage of the total weight.

Also, the amount of oversize chips (Case Study 2) could be explained by the material being processed (limbs and tops vs. whole trees). With whole-tree chipping, the trees are brought to the loader butt first, and the loader places them butt first into the chipper. With the stems moving in a longitudinal manner, the wood is introduced to the knives at a consistent angle, resulting in the desired chip size. Only the limbs would meet the knives at different angles, resulting in different size chips. In Case Study 2, the material was limbs and tops from a pulpwood thinning operation. When the residue started to accumulate, it was pushed back into a pile. With the chipping operation, a skidder operator would back up to the pile and with the grapples take a "bite" and drag it to the loader. The loader operator would pick it up and place it at the infeed of the chipper, however convenient. Therefore, much of the material did not contact the knives at the desired angle.

Both Case Study 3 and Case Study 4 were sites of mature pine plantations in which hardwoods such as oak and sweetgum invaded prior to clear-cutting. In processing these hardwood sapling stems, the motor on the large grinder (Case Study 3) would slow down, and the output included long strands (6 to 12 in.), resulting in 7.2 percent oversize material. The smaller motor on the Case Study 4 grinder slowed way down with the hardwood stems, resulting in even longer strands and 30.6 percent oversized material. The operation in Case Study 5 processed residues from a second thinning of a pine plantation; therefore, there was

*Table 5.—Mean vlues of percentage of sample weight, percent moisture content (MC), British thermal unit value per ovendry pound, and percent ash content by particle size of residues processed by a large horizontal grinder less than 1 year after a second thinning harvest of a loblolly pine plantation.*[a]

| Size (in.) | % of wt | % MC (dry basis) | Btu/lb | % ash |
|---|---|---|---|---|
| Pan | 7.7 | 177.5 | 7,664 B | 12.6 A |
| >⅛ | 22.0 | 181.8 | 7,957 BA | 7.6 B |
| >¼ | 31.0 | 151.8 | 7,904 BA | 4.5 C |
| >½ | 17.5 | 121.2 | 8,261 A | 2.0 D |
| >⅞ | 10.5 | 116.5 | 8,211 A | 1.9 D |
| >1¼ | 5.3 | 81.5 | 8,254 A | 1.2 D |
| >1¾ | 6.0 | 81.5 | 8,254 A | 1.2 D |
| Average | NA | 143.4 | 8,029 | 4.7 |
| Loaf pan | NA | 144.3 | 8,460 | 5.3 |

[a] The site was wet because of an extended period of rain prior to residue harvest. Within a column, values followed by the same letter are not significantly different. NA = not applicable.

little or no hardwood residue to be ground, and larger amounts in the smaller size classes resulted.

Beveridge (1950) stated that researchers tend to focus so intently on their goals that they do not see peripheral effects or ideas. A peripheral idea with this study concerned the fine material from the grinders. It was mentioned that the finer material from the grinders looked similar to potting soil. If the logger were to install a shaker screen to separate the material smaller than ¼ inch and load the remainder onto the van, the larger material going to the energy facility would have a higher Btu value and a lower moisture content than the current mixture going to the facility. Locally, a 2-cubic-foot (45- to 50-lb) bag of potting soil sells for $9.00. If one were to expand the weight and value to a ton ($400) and then reduce for retailer markup (100%), wholesaler markup (100%), and producer costs, the material should still have a value of $50 per ton or more.

If one were to use the data from Case Study 3 (Table 3) as an example, the average moisture content is 62.6 percent on a dry basis, and the average Btu value is 7,713 per ovendry pound. If one removed the previously mentioned finer material, then the average moisture content would be reduced to 58.3 percent, and the Btu value would be increased to 7,853 Btu per ovendry pound. A 25-ton truck load currently would have 237 million Btu, whereas a truckload of the new mixture would have 248 million Btu. This would be nearly a 5 percent increase in Btu's delivered to the energy facility. In addition, there would be a large decrease in the amount of ash the facility would have to deal with. Similar analyses could be conducted on the other grinder case studies (Table 6). With the chipper case studies, the fines had a higher Btu value and lower moisture content, although they had higher ash content.

*Table 6.—The percent change in weight, moisture content (MC), ash content, and British thermal unit values per overdry pound when the fines (<⅛ or <¼ in.) were removed.*[a]

| Change | Case Study 3 | | Case Study 4 | | Case Study 5 | |
|---|---|---|---|---|---|---|
| | <⅛ | <¼ | <⅛ | <¼ | <⅛ | <¼ |
| Weight | −11.5 | −25.0 | −7.6 | −15.4 | −7.7 | −29.7 |
| MC | −13.0 | −28.2 | −10.0 | −18.9 | −9.5 | −37.4 |
| Ash | −52.7 | −66.5 | −54.8 | −64.3 | −20.5 | −56.0 |
| Btu/lb | +10.6 | +24.1 | +6.3 | +14.1 | +7.3 | +29.1 |

[a] − and + = a reduction and an increase in value, respectively.

## Conclusions

The goal of this study was to determine the general characteristics of processed in-wood biomass. If the energy facility were buying from chipping operations, then they might consider an average of the two operations studied (94.2% moisture content, 8,168 Btu per ovendry pound, and 1.2% ash content). If the facility's suppliers are grinders working on old harvest sites, then the average of those three case studies should be considered (83.0% moisture content, 7,785 Btu per ovendry pound, and 4.5% ash content). Energy facilities in the study area purchase from all five of the operations; therefore, they should consider the overall average of 87.0 percent moisture content, 7,945 Btu per ovendry pound, and 3.1 percent ash content. Since this study dealt with five independent case studies, the results should be used with caution, as they are just indications of the biomass supply.

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