TECHNICAL NOTE

Characteristics of Forest-Derived Woody Biomass Collected and Processed in Oregon

David Smith John Sessions Kevin Tuers
Daniel Way Jeff Traver

Abstract

We present a summary of the characteristics of 55 samples of processed forest biomass residues randomly collected from 34 sites in Oregon. Our purpose is to illustrate the wide diversity of field-processed grindings and chips that are currently being produced to inform managers of the potential variability in existing biomass sources. The samples vary widely with respect to moisture content, particle size distribution, species mix, and ash content. We discuss the value of residue classification for downstream processing. The primary use of forest residues is currently for combustion, but stratification of forest residues provides opportunities to create value-added products, provide rural employment, and increase transportation efficiency.

The State of Oregon has placed emphasis in recent years on growing its biomass industry. In 2005, Senate Bill 1072 established the Forest Biomass Working Group (2005) to accomplish the biomass goals of then Governor Kulongoski's Renewable Energy Action plan. This led to the creation of the Biomass Producer or Collector Tax credit in 2007 (US Department of Energy 2012), which accelerated the collection of forest biomass through payment of $10 per green ton for materials used in certified renewable energy facilities. This incentive continues to be offered, albeit at a reduced rate of $10 per bone dry ton. The impact of these policy actions was an accelerated interest in collecting forest biomass for energy production. Many projects were evaluated, and some built, to use woody biomass to generate process steam and power and to heat institutions and communities.

This bulky, low-value material comes from two primary sources, logging slash and precommercial thinnings, both of which are susceptible to contamination with dirt and rocks. The technology commonly used for processing and transporting woody biomass from the forest to the energy plant begins with accumulating the material in piles at a location (landing) accessible to trucks. The small diameter stems, tops, branches, defective pieces, and low-grade logs are then fed into either a grinder or chipper for size reduction and loaded by belt conveyor into a chip van for transport to the energy conversion facility (Fig. 1). Alternatively, but less frequently, the coarse biomass is transported to a plant site for processing.

One of the lessons quickly learned was that unlike mill residues, forest-derived biomass can be difficult and expensive to collect, transport, and use. This material is highly variable in moisture content and physical form, making it difficult to process into a uniform feedstock for energy production. Field collection methods to build piles for size reduction and truck loading can introduce grit and rock contaminants that can damage equipment and complicate firing in furnaces and gasifiers.

The energy market for forest biomass in Oregon is currently dominated by large power and combined heat and power operations. The combustion technologies used in these facilities ranges from older stationary grate hog fuel boilers to modern fluidized bed furnaces with staged-combustion gasifiers. Most of these facilities are equipped with rugged material handling equipment and combustion controls capable of dealing with some degree of feedstock variability. However, the recent surge in forest biomass supplies has resulted in operational problems with bridging

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The authors are, respectively, Instructor, Dept. of Wood Sci. and Engineering (David.smith@oregonstate.edu [corresponding author]) and Professor, Dept. of Forest Engineering, Resources, and Management (John.sessions@oregonstate.edu), College of Forestry, Oregon State Univ., Corvallis; Biomass Manager, Seneca Jones Timber Co., Eugene, Oregon (ktuers@senecasawmill.com); Log Yard Supervisor, Northwest Hardwoods, Eugene, Oregon (dan.way@northwesthardwoods.com); and Undergraduate Student, Dept. of Wood Sci. and Engineering, College of Forestry, Oregon State Univ., Corvallis (traverj@onid.orst.edu). This paper was received for publication in October 2012. Article no. 12-00109.

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Figure 1.—Field processing of logging slash in southwest Oregon. (Left) Peterson-Pacific horizontal grinder. (Right) Bruks horizontal chipper.

and blocking of fuel handling systems, overloading of ash removal devices, furnace slagging, scale formation on boiler tubes, and problems with particulate control devices. Some of these operators, such as Seneca Sawmill Co. (Fig. 2) in Eugene, Oregon (Seneca Sawmill Co. 2012) are attempting to work with suppliers to improve the biomass feedstocks by establishing better quality specifications. However, quality specifications presently in use tend to be vague, internally generated, and lack reference methods for measuring compliance.

The other emerging market segment for solid biomass fuels is in smaller scale thermal applications to heat schools, hospitals, and clusters of commercial and public buildings (district heating). One of the more successful, and larger, examples of this is the Seattle Steam installation that provides heat to 200 buildings in Seattle's central business district (Seattle Steam 2012). In 2009, Seattle Steam installed a state-of-the-biomass boiler to improve fuel flexibility and reduce carbon emissions. On a smaller scale, the school district in Enterprise, Oregon, recently installed a wood chip heating system designed to use low-grade forest biomass (Weeks 2009). However, the operation has struggled to realize the projected energy savings because of operational problems caused by feedstock quality.

Enterprises' problems with using forest biomass have resulted in other prospective small-scale users looking for other renewable fuel alternatives, such as wood pellets (Kaufman 2011a, 2011b). Pellets, usually produced from clean mill residues (Lu and Rice 2010), are up to five times more expensive than forest-derived biomass fuels but can still be cost effective while providing the clean-burning, trouble-free operation that schools and institutions need (Pellet Fuels Institute 2012).

The move from forest-derived biomass to pellets for small-scale thermal applications has been a disappointment for biomass energy advocates. The opportunity for using local forest residues to provide local energy independence seems to be slipping away because institutional project managers are reluctant to take on the operational risks created by a highly variable feedstock. They seem to be willing to trade the potential savings from low-cost biomass fuel chips for the reliability of fuel pellets produced to comply with tight performance specifications (Pellet Fuels Institute 2011).

The situation in Oregon, which is typical of western operations, is different from the situation in the Northeast United States, where institutional and district heating operations are more common. In that region, woody biomass fuels are mostly derived from chipping roundwood, rather than from grinding forest residues. Quality specifications have recently been established to inform both producers and users on performance requirements and cost options in order to create a more manageable marketplace that allows project planners to design fuel handling systems around known fuel characteristics, and operators to evaluate trade-offs between operational risk and fuel supply costs (Biomass Energy Resource Center 2012).

This recognition of the need to provide some order to the biomass fuels marketplace is spreading with society's desire for more sources of renewable, low-carbon fuels. In 2007, the International Organization for Standardization (ISO) organized Technical Committee 238 (TC 238) to develop ISO standards for solid biofuels (American Society of Agricultural and Biological Engineers [ASABE] 2012). In the United States, participation in this effort is coordinated through the ASABE. At the present time, ISO records show participation in TC 238 has grown to 33 countries working in six major areas to establish classifications for solid biomass fuels and standardize sampling and measurement procedures. The scope of the effort addresses pellets, briquettes, cord wood, and fuel chips made from both woody and nonwoody biomass feedstocks. Of particular interest is proposed standard ISO/DIS 17225-1 ''Solid Biofuels—Fuel Specifications and Classes—Part 1: General Requirements.'' When promulgated, it will create separate classifications and property specifications for various

Figure 2.—Seneca Sustainable Energy Cogeneration plant, May 27, 2011. Photo courtesy of Seneca Sawmill Company.

sources of woody biomass including wood chips and hog fuel. It establishes grade classifications for important characteristics such as particle size distribution, moisture content, noncombustible ash content and make-up, bulk density, and energy density. Equally importantly, the standard establishes testing protocols by reference to other standard methods for sampling and property measurement (ISO 2013).

The aim of the work presented here is to assist both the ASABE/ISO effort to classify solid biomass fuels and the regional marketplace by reporting our findings from analyzing processed forest-derived biomass fuels collected from commercial operations in Oregon over a 2-year period.

Methods

A total of 55 samples of woody biomass fuels commercially prepared from forest residues were collected from 34 sites and analyzed for critical characteristics of particle size distribution, moisture content, ash content, bulk density, and energy density. These were, for the most part, samples of opportunity. That is, they were collected when the opportunity arose, rather than according to a predetermined plan. We did not design or conduct a ‘‘cause and effect’’ experiment. The goal of our study was simply to measure important quality characteristics of as many samples of commercially prepared woody biomass fuels as limited resources would allow, rather than test variable interactions.

Thirty of the samples originated in Oregon’s western/coastal forest region and were made up of mostly Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), or mixed softwoods. Nineteen came out of central Oregon’s pine/juniper region, and the rest from Northeast Oregon’s intermountain forests. Most of the samples were collected in the field by the investigators or their industrial partners. Twelve samples were collected by Seneca Sawmill Co. from deliveries to their Eugene cogeneration facility. Whenever possible, and in all but a few of the cases, the sample size was 40 to 80 liters, and were composites of a set of grab samples, each 4 to 12 liters in size (Fig. 3).

The samples were analyzed for key characteristics in the College of Forestry laboratories at Oregon State University. They were first sampled for moisture content, and then passed over a 20 by 45-inch Rotex oscillating horizontal screener (Fig. 4) for separation into three size fractions. The screener was fitted with a 50-mm (2-in.) round hole top deck and a 10-mm (3/8-in.) round hole bottom deck. This fractionation method was selected for its practicality for industrial application. These types and sizes of screens can be run at production rates with little operational difficulty, and they do a good job of separating acceptable material from potentially undesirable material. Large particles retained on the top deck were classified as ‘‘overs,’’ and small particles passing through the bottom deck were termed ‘‘fines’’ (Table 1). Material retained between the decks was called ‘‘mids.’’ This mids fraction is mainly composed of particles whose largest dimension ranges from 75 to 12 mm (3 to 1/2 in.), which is regarded as near-ideal for most industrial boiler applications. Many of the samples were further size classified by largest particle dimension of the coarser fractions and sieving of the finer material (Table 1).

Figure 3.—Typical size of a woody biomass sample.

Figure 4.—Fractioning screen.

All moisture determinations were made by 24-hour oven drying at 103°C ± 2°C. Moisture content, wet basis, and dry solids content were reported as the average of triplicate measurements of the fractional portion of moisture, or ovendry (OD) solids, in the sample at time of test. Dry solids content is preferred by the marketplace because deliveries are usually paid on a dry solids basis, and it allows easy determination of the dry weight of a trailer load.

Noncombustible (ash) content was measured on the aggregate of each sample and each of the three screen fractions. The aggregate, overs, and mids fractions were first hammer milled in a 6 by 18-inch Jenkins 15-hp mill 3/8-inch screen plates to produce small particles. The fines fraction was tested as screened. Each material was mixed thoroughly and then parsed down by coning and dividing into small enough specimens to fit in 50-mL porcelain crucibles (approximately 4 to 8 g OD). The materials were dried in the crucibles for 24 hours to determine OD weight, placed in a cold muffle furnace without lids, and then incinerated according to ASTM D1102-84 (ASTM International 2007) at 600°C until all visible char was removed. Ash content was determined in triplicate as the noncombustible portion of the original OD mass. In some cases, visible rocks were removed from the sample fraction prior to hammer milling, and their contribution added to measured noncombustible content.

Bulk density was measured on the aggregate and mids and fines fractions of each sample by loading the green

Table 1.—Typical particle size distribution of a field-processed forest biomass sample comparing three screen fractions and largest particle dimensions.

Size fraction	Screen range (mm)	% green wt in fraction	Largest dimension (mm)	% green wt in fraction
Overs	>50	7.9	>150	2.9
			75–150	19.4
Mids	10–50	79.9	6–75	65.6
Fines	<10	12.2	1.5–6	8.8
			<1.5	3.3
Total		100.0		100.0

material a handful at a time into either a 2- or 10-liter container of known volume. The bulk density of the overs fraction was not measured. Bulk density of biomass samples is challenging to measure. Others have proposed pouring the sample from a prescribed height into a known volume, but we chose to shake the containers slightly during loading to overflow and skimming to volume. This method was developed internally and provided good reproducibility between replicates. Measurements were made in triplicate. Bulk density, as received (BD_{ar}), was reported as the average weight per volume of the three measurements. Bulk density, dry basis, or ''basic bulk density'' was calculated by multiplying BD_{ar} by the percentage of solids (determined at the time of test) as prescribed by ISO WD XXXXX (15103).

Energy density was also measured on the aggregate material and each of the three screen fractions. The same subsamples prepared for noncombustible determination by hammer milling were used. Test specimens were selected from a well-mixed bag of material. Energy density was measured using an IKA Model 200 bomb calorimeter system. Gross energy density or higher heating value (HHV) measurements were made on ovendry material. Net energy density or lower heating value (LHV) was determined by measuring the heat released from samples tested at original moisture content.

Results and Discussion

We found that woody biomass collected and processed in the field for energy generation shows wide variations in all of the key characteristics measured. Although this study was not designed to evaluate interactions of process variables, it appears that collection methods, processing equipment, species, site conditions, and time intervals between harvest and processing all influence material characteristics. Consequently, we regarded the samples as each coming from different populations, so the application of statistical tools to describe their variation was not applicable. We have chosen to describe our findings in terms of mean, median, and range values (Table 2) and histograms (Figs. 5 through 10) to give an indication of total variation.

The average moisture content (wet basis) of the 55 samples tested was 40 percent. Individual samples varied widely, from less than 20 percent to more than 60 percent, with most samples falling within the 30 to 50 percent range (Fig. 5; Table 2). Although the study was not designed to evaluate interactions, we did observe that the samples at the low end of the moisture range were collected from locations where the raw biomass had been piled for several dry months prior to processing, and that samples with a moisture content above 50 percent were either processed during the rainy season or were generated by log debarking or pole peeling operations.

Particle size distribution, as characterized by gross screen fraction, averaged 5 percent overs, 70 percent mids, and 25 percent fines (Table 2). Again, although the study was not designed to evaluate interactions, we observed that the samples with lowest overs fractions were generated by either chippers or mill hogs (Fig. 6). Material processed by horizontal grinders and tub grinders tended to produce higher overs content. Although not evaluated, factors that might influence the generation of oversized particles included high moisture content, wood species, and grinder configuration and loading rate.

We observed that low fines content, <15 percent, was generally associated with chipper processing. Many of the samples exhibited a high fines content (>25%). It appears that many causes can contribute to high fines, including needles and twigs, grinder grate and teeth configurations, and double passing through a horizontal grinder to reduce overs. Heavy contamination with dirt and rocks, as evidenced by an apparent relationship between high noncombustible ash content, appears to also be closely associated with high fines.

Bulk density of biomass fuel samples can be expressed as either total or dry mass per unit volume. It is important to understand the distinction for transportation and handling equipment design purposes. Wet bulk density (total mass per unit volume) varies widely and appears to be influenced by moisture content, noncombustible content, size distribution, and feedstock (Fig. 7). Certain species, such as vine maple (*Acer circinatum*) and Western juniper (*Juniperus occidentalis*), were observed to tend toward low bulk density, particularly when the feedstock was heavier to limbs than stems. Dry bulk density (dry solids per unit volume) shows less variation.

Noncombustible (ash) content in biomass fuel samples tends to run much higher than the true ash content of wood, indicating contamination with dirt, rocks, and wind-blown dust. The anatomical ash content of woody biomass is similar to that of solid wood and bark; almost always less than 1.0 percent and often under 0.5 percent (Browning 1963). Anything higher than that is due to contamination. Overall noncombustible content of the biomass fuel samples tested averaged 6.0 percent with a median value of 3.2 percent (Table 2). About half of the samples had <3 percent noncombustible material, with higher to much higher values in the rest (Fig. 8a) indicating high contamination with noncombustible material. We found that much of this contamination becomes concentrated in the fines fraction after screening (Fig. 8b). This is similar to observations by others (Zhang et al. 2012). Although this fraction usually comprises only about a quarter of the total mass, it can

Table 2.—Key characteristics of forest-derived woody biomass.

Key characteristic[a]	All samples Mean	All samples Median	Range Maximum	Range Minimum	Total data points
Moisture content (% wet basis)	39.7	38.4	66.0	12.3	55
Screen fraction (%)					
Overs	4.9	4.3	12	0	52
Mids	70.0	69.6	98	6	52
Fines	25.2	25.8	94	2	52
Bulk density (kg/m^3)					
Wet	266	256	432	108	51
Dry	150	146	224	72	51
Ash content (% of dry wt)					
Total	6.0	3.2	26.7	0.3	55
Fines	14.1	9.2	44.8	0.3	52
Energy density (MJ/kg)					
HHV	19.7	20.0	21.6	11.5	52
HHV of fines	19.2	19.3	22.1	14.7	50
LHV	11.7	12.0	16.8	5.0	50
LHV of fines	9.6	9.2	14.9	4.0	36

[a] HHV = higher heating value; LHV = lower heating value.

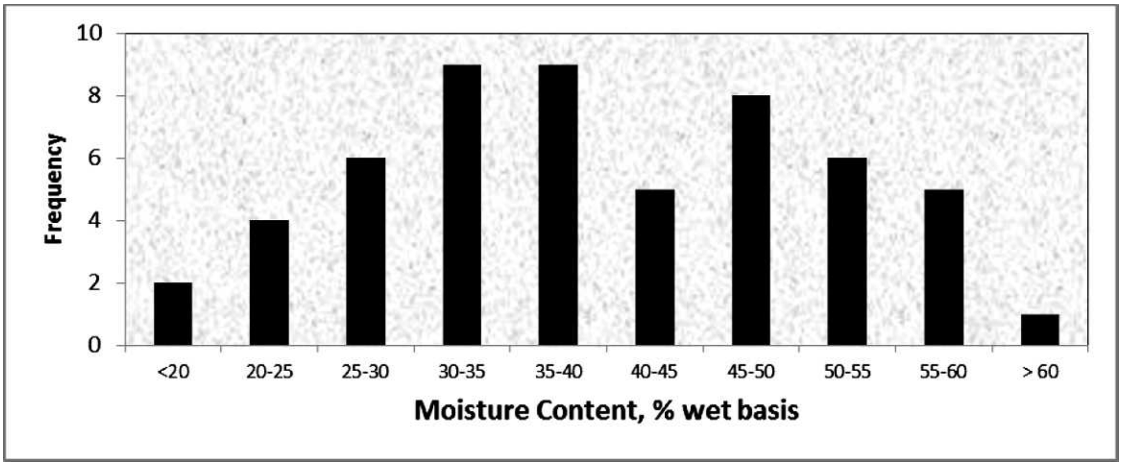

Figure 5.—Distribution of moisture content in biomass fuel samples.

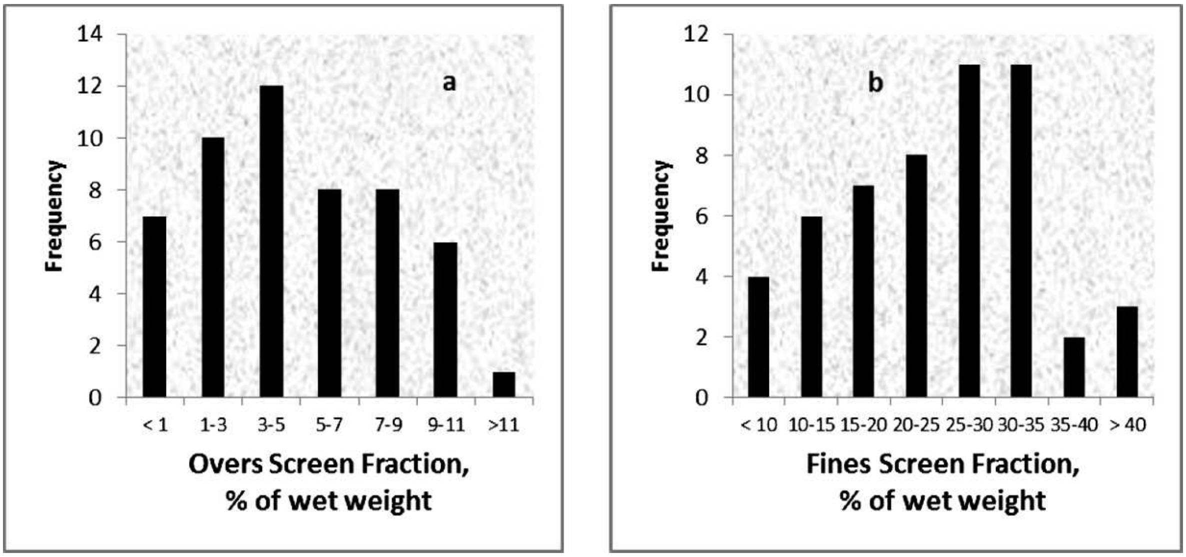

Figure 6.—Distribution of (a) overs and (b) fines in biomass fuel samples.

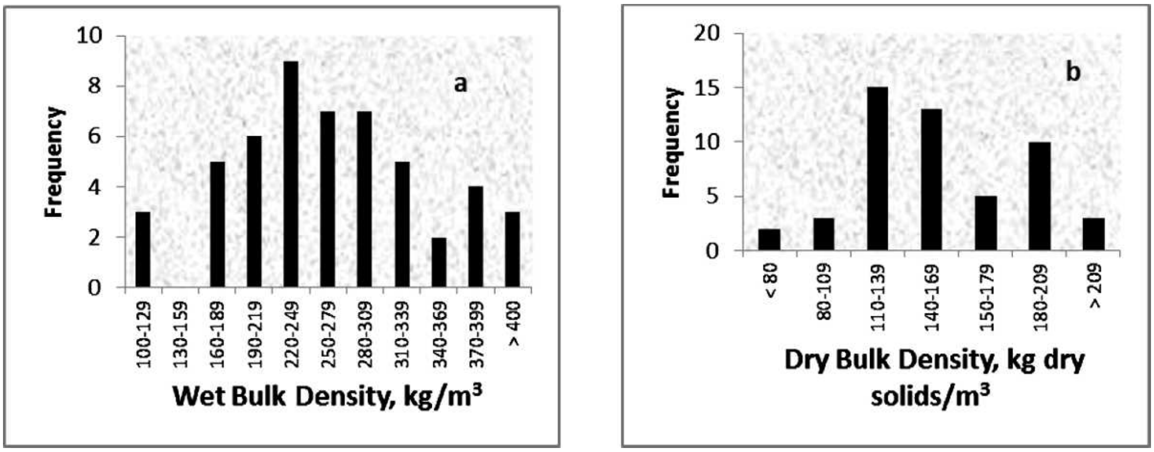

Figure 7.—Distribution of (a) wet and (b) dry bulk density of biomass fuel samples

contain over 90 percent of the noncombustible material in highly contaminated biomass fuel preparations. We observed that samples with the highest total noncombustible content and noncombustible fines content came from land clearing operations or from the reclamation of old material piles that were hard to reclaim because of consolidation. Chipping operations where operators exercised care to avoid knife damage from dirt and rocks by presorting and discarding smaller, dirtier material tend to show low noncombustible content.

HHVs for the biomass fuel samples (Fig. 9a) tested generally fall within the 18.5 to 21 MJ/kg (7.9 to 8.9 kBtu/lb) range suggested by Ince (1979). The HHVs of the fines fractions (Fig. 9b) are generally lower, reflecting higher noncombustible ash content. The highest values for both the total samples and fines fractions may reflect higher proportions of bark, which has a slightly greater HHV in conifer species than wood (Browning 1963).

LHVs, which were measured on the samples as received, showed a wide range of from less than 8 MJ/kg (3.4 kBtu/lb) to over 16 MJ/kg (6.8 kBtu/lb; Fig. 10), which reflects the wide range in moisture content previously noted. The concentration of LHVs for the fines fraction at the low end of the range may be related to higher noncombustible ash content in the fines fraction (Fig. 10b).

Management Implications

The range in particle size distribution, bulk densities (dry and wet), heating values, and noncombustible ash content of forest-derived woody biomass fuels have important impacts for both suppliers and purchasers of these materials. Just as log scales have been important for classifying the value for solid wood products, classification of forest biomass materials would provide similar benefits. Buyers and sellers would have better knowledge of the feedstock they are dealing with. This understanding provides the opportunity to identify characteristics that either add to or detract from the material's end-use value, and to price it accordingly.

The management consultant Peter Drucker reportedly said ''If you can't measure it, you can't manage it'' (Drucker 2006). Particle size distribution, moisture content, and noncombustible ash content, once measured and classified, are all subject to management. A classification system stimulates management to look for ways to efficiently achieve specifications. The very different characteristics of the overs, mids, and fines fractions suggest the potential for product differentiation or conditioning.

If the end use is direct combustion, high moisture content lowers fuel value for the purchaser. Not only is significant energy required to evaporate the moisture in the fuel, but the resulting vapor volume adds significantly to the fan energy

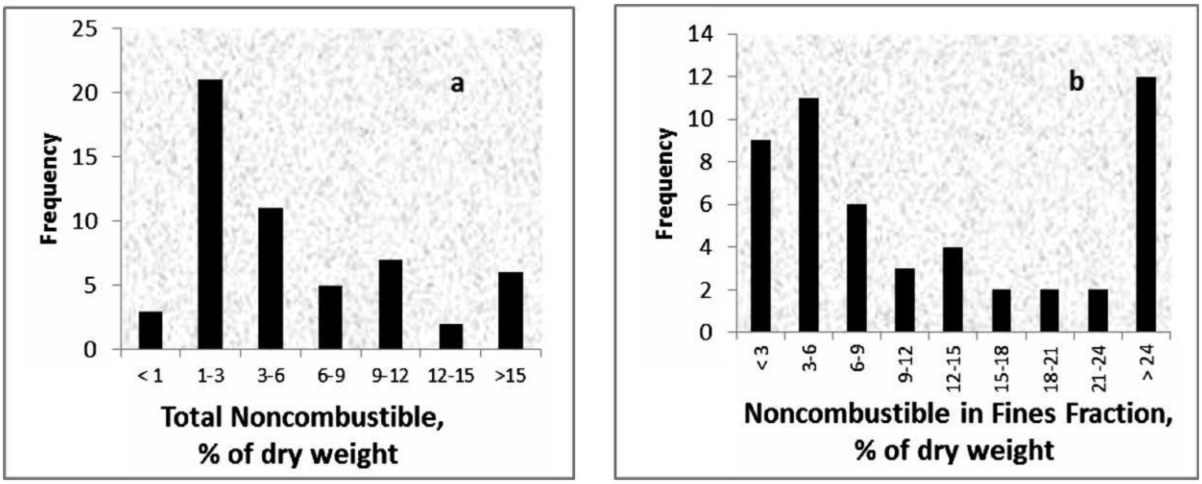

Figure 8.—(a) Total noncombustible content and (b) fines noncombustible content of biomass fuel samples.

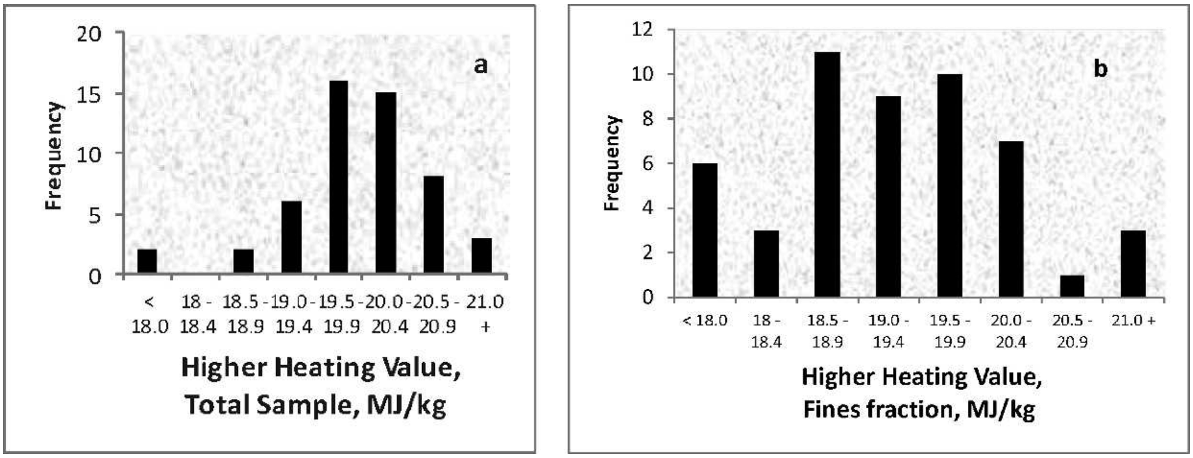

Figure 9.—Higher heating value of (a) all fuel samples and (b) fines fractions.

required to move the total exhaust volume through the system. It impacts pollution control equipment performance and the opportunity to recover exhaust heat before approaching dew point. High moisture content also increases transportation costs for the supplier. The difference in energy value between a 20,000-kg fuel payload at 40 and 30 percent moisture content is about 23.2 GJ (22 MMBtu). Moisture content can be managed through field drying before comminution. Field drying also permits needles to drop, reducing noncombustible ash and fines content.

Particle size distribution impacts a material's run-ability and handling characteristics at the point of use. High overs content can cause bridging in storage silos and block discharge points and conveyor transitions. The fuel handling systems designed for large-scale industrial boilers may be able to deal with a reasonable portion of large particles, but the smaller equipment typically designed for an institutional heating system can be quickly crippled by even a small portion of overs. High fines content can likewise cause combustion air distribution issues in grate-style boilers but may be desirable or of no consequence with other furnace designs.

Low dry bulk density may influence supplier transportation costs by filling trailer to volume capacity before reaching load weight limits. Processing equipment and material condition influence the bulk density of processed material; however, patterns are difficult to discern from the data. Particle shape and size distribution definitely have an impact. Chipping tends to produce higher bulk density than grinding, particularly with species such as Western juniper or vine maple. Samples with high overs content tend to have lower dry bulk density, while high fines content leads to higher dry bulk density. In the field, loading method (blowing vs. conveying) will also affect the mass of material that a trailer will hold. All other things being equal, lower dry bulk density requires the use of larger (longer) trailers for transport and higher standard roads for access and turnarounds.

Noncombustible content directly reduces fuel value and creates handling issues and disposal problems at the plant, which increase costs. Noncombustible content is a function of bark and needles percentage and dust, dirt, and rock contamination. The content of noncombustible ash on the HHVs and LHVs of the fines fraction is noticeable (Figs. 9 and 10). Precomminution, noncombustible contamination content can be managed by avoiding pushing piles together with tractors, running over piles with skidders, or trying to fully recover piles by scratching in the dirt. Postcomminution, it can be reduced by screening the processed material to remove the fines fraction. The most economical location to do postcomminution upgrading of residues is still to be

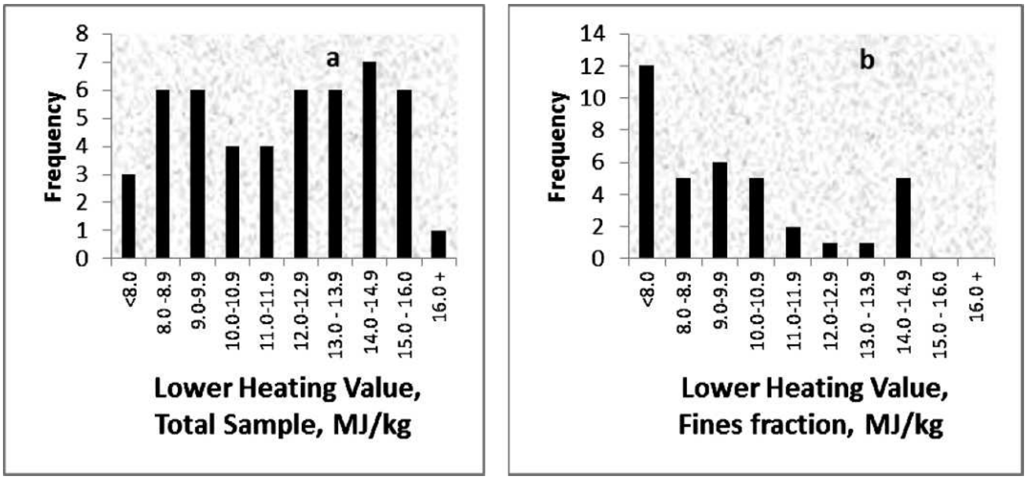

Figure 10.—Lower heating value of (a) all fuel samples and (b) fines fractions.

determined. Options include at the residue site, at a satellite yard, or at the plant. The decision may depend upon existence of markets for different grades and transportation costs. Removal of fines before energy conversion can significantly increase total fuel value by lowering both fuel moisture content and noncombustible content. This can have an overall net economic benefit if soil amendment or other suitable markets can be found for the fines.

At the present time, the application of grade classifications or quality specifications for woody biomass fuels is not widespread. Those that are in place have been mostly created internally by large industrial/utility purchasers and are not based on consistent terminology or test methodology.

There is growing interest in the institutional, commercial, and district heating markets for renewable energy fuels. However, performance problems associated with variations in fuel quality characteristics in a few early projects are limiting market growth. In Oregon and the Northwest, new, smaller scale projects are now more commonly designing operations around pellet fuels because of their ease of operation. The uniformity of grade-classified pellets allows operators to minimize their operational risk and accurately estimate their fuel costs. Although fuel pellets are considerably more expensive than the woody biomass fuels examined here, institutional managers are willing to trade the savings for trouble-free operations.

Establishment and acceptance of a grade-classification system that allows designers of smaller scale thermal systems to accurately and reliably understand their choices for solid woody biomass fuels could stimulate market growth. It seems practical, that with some additional processing, forest-derived woody biomass fuels could be made and supplied at an intermediate price point between industrial hog fuel and pellets. The supply of an ''institutional fuel chip'' is an unmet market need in Oregon. Its availability is dependent upon creation of a system that will relieve the present confusion in the market by establishing a classification system that allows buyers to define their requirements in understandable and verifiable terms, and suppliers to manage their production operations to highest value.

Present efforts by ISO and ASABE to establish standards for solid biofuels are strong first steps. The draft standards presently under development need to be evaluated for their usefulness and applicability to the thermal energy market in Oregon and the western region. The methods used here to test biomass fuel characteristics are not consistent with those incorporated into the draft ISO standards, so direct evaluation of their applicability is not possible. Further study should be conducted to understand whether these draft standards, as designed, will serve the market need.

Concluding Remarks

We have summarized our findings from analysis of 55 samples of randomly selected forest-derived woody biomass collected and processed by commercial operations in Oregon over a 2-year period by presenting graphs and tables that show the range and pattern of variation of several key quality characteristics. The reader should note that this study was not designed to test interactions with process variables that might influence these quality characteristics. Our purpose was simply to generate information on what is currently occurring in the commercial marketplace. We note that the large variations observed in particle size distribution, bulk density, moisture content, and noncombustible ash are signs of an evolving industry. Development of residue classification systems, expanding markets, and continuing equipment development may markedly change the characteristics of tomorrow's woody biomass derived from western forests. Future steps including structured tests of interactions between process variables and quality characteristics will be useful to inform managers on the costs and methods for reaching solid biomass fuel specifications.

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