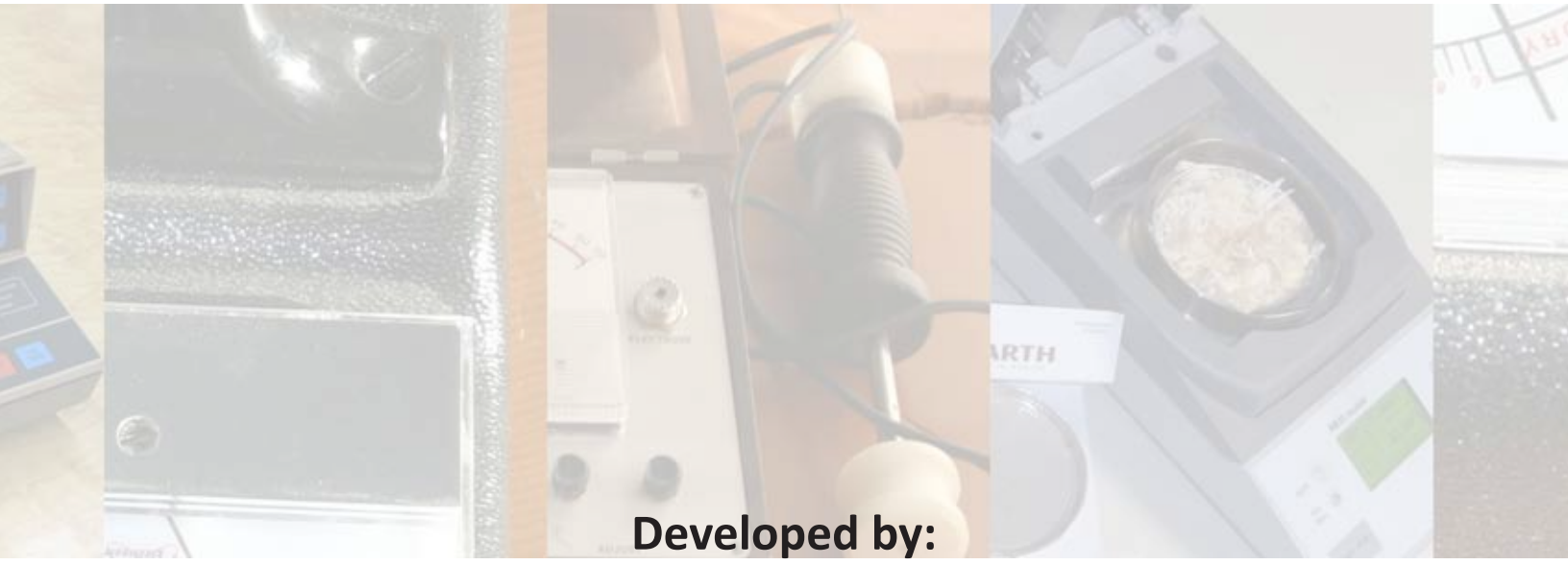
A PRACTICAL GUIDE FOR THE DETERMINATION OF MOISTURE CONTENT OF WOODY BIOMASS

A Practical Handbook of Basic Information, Definitions, Calculations, Practices and Procedures for Purchasers and Suppliers of Woody Biomass



Developed by:

Robert Govett, University of Wisconsin-Stevens Point
Terry Mace, Wood Utilization and Marketing, Wisconsin DNR
Scott Bowe, University of Wisconsin-Madison

A PRACTICAL GUIDE FOR THE DETERMINATION OF MOISTURE CONTENT OF WOODY BIOMASS

Overview

Use of woody biomass such as mill residues and forest residues is not a new practice by any stretch of the imagination. There is a long and widespread tradition of the use of woody biomass in energy applications such as a boiler fuel, and it represents a very large fraction of the total renewable energy produced in Wisconsin and across the United States. Interest in increased use of woody biomass has grown significantly in recent years, particularly in the Lake States, with increased conversion or replacement of fossil fuel fired boilers to the use of woody biomass and with consideration of woody biomass as a feedstock for the production of biofuels. While many sectors within the forest industry, such as sawmills, veneer operations, chip mills, pulp mills and all types of secondary manufacturers routinely deal with moisture content of wood, other sectors of the industry such as loggers and practicing foresters have typically had much less need to concern themselves with moisture content determination. Additionally, the basis and methods of determining moisture content are quite variable depending on the products being dealt with and the sector of the industry being represented.

With the expanded use of woody biomass, loggers, foresters and others within the industry (and some people from outside the industry) are now being forced to understand and deal with wood moisture content issues. For example, loggers or foresters that may have sold woody biomass on a green ton basis may soon need to understand the practical aspects of selling the same woody biomass on a dry ton basis. Also boiler operators outside of the industry need an understanding of wood moisture determination in fuel acquisition and testing. This paper is designed to serve as a practical guide for anyone in the Wisconsin industry in understanding the issues related to determination of moisture content of woody biomass and reasonable methods that can be used to determine moisture content of woody biomass in an industrial setting.

Woody biomass can be composed of wood (in the form of some kinds of mill residues such as sawdust, trim ends, etc.), or bark (typically that has been removed in a debarking process), or a combination of wood and bark (such as cull logs or bolts, chipped tree trimmings etc.). Also the forms of the material can vary considerably, ranging from roundwood of various sizes and lengths, slabs, edgings, sawdust, hogged fuel, and whole-tree-chips and also in the form of recovered residue such as branchwood that may include some fraction of needles. For purposes of simplicity in this paper, the term “wood” in discussion will be used as a generic term for woody biomass in all its various forms in calculations and discussions for which the calculation would be the same for wood (xylem) or woody biomass.

The basis on which moisture content % is determinded (i.e. MC as a % of what?)

There are two common ways in which the moisture content percentage (MC%) of wood is routinely expressed.

GREEN BASIS: In the green or wet basis (usually abbreviated "Green basis") method, the percent moisture in the wood is expressed as a percentage of the TOTAL weight of the wood, including both the dry wood material and the water. This method is most commonly used for pulp chips and hogged fuel and **this method is generally the method used to determine the MC of woody biomass**. It is computed as follows:

$$\text{MC\% (Green basis)} = \left(\frac{\text{weight of water}}{\text{weight of water + dry weight of wood}}\right) * 100$$

OVENDRY BASIS: In the ovendry basis (usually abbreviated "OD basis") method, the % moisture in the wood is expressed as a percentage of the dry weight of wood. This method is the standard method used in this country to express moisture content for solid wood products of all kinds including lumber, veneer, plywood, OSB, particleboard and other panel products.

$$\text{MC\% (OD basis)} = \left(\frac{\text{weight of water}}{\text{dry weight of wood}}\right) * 100$$

In terms of an example, assume you have taken a sample of woody biomass equal to 100 grams in total weight, and you are able to determine that the sample consists of 49 grams of dry woody biomass material (after water equal to 51 grams is removed), the moisture contents would be calculated as follows:

$$\text{MC\% (Green basis)} = \left(\frac{51}{100}\right) * 100 = 51\% \text{ MC (Green basis)}$$

And, for THE SAME SAMPLE:

$$\text{MC\% (OD basis)} = \left(\frac{51}{49}\right) * 100 = 104\% \text{ MC (OD basis)}$$

It is important to note that both of these methods of determining moisture content are appropriate and are commonly used. There is good reason to use the ovendry basis for measuring moisture content in solid wood products. For example, where calculations may need to be made regarding changing moisture contents over time using periodically measured sample pieces (such as sample board in a dry kiln), in using the ovendry basis method, the denominator in the equation would not change for the piece for the string of calculations to estimate moisture content at various times in the drying process. In a similar vein, there is good reason to use the green basis method for pulp chips and fuel, where it is used for a one-time point estimate of what fraction of the whole is usable fiber (or fuel) and what fraction is water. As you will note, in the example provided above, the OD basis moisture content can (and will) exceed 100% on occasion – this is NOT an error – it simply reflects that the weight of water in the sample exceeds the weight of dry material (this is quite common in many circumstances in Wisconsin, such as with aspen in the winter, and for many softwoods and some lower density hardwoods). **In any context regarding the expression of moisture content of woody biomass in an industrial setting it is essential that all parties concerned understand the basis on which the moisture content is determined and expressed.** For this reason, it is highly desirable (if not essential) to clearly express the basis on which the moisture content was determined. **It is so easy to succinctly, clearly and accurately express "MC (OD basis)" or "MC (Green basis)" - which are two very different things – that it would be utterly foolish to simply express "moisture content" or "MC" (without any expressed basis) and create the potential for confusion.** This potential for confusion (and contract disputes, disagreements etc.) can largely be avoided by simply specifying the basis being used to express the percentage moisture content. In almost all cases in transactions regarding woody biomass it will probably be the case that using the Green basis moisture content would be used – but there are circumstances where MC may be determined using the OD basis and conversion could be required, prompting confusion.

TO CONVERT OVENDRY BASIS %MC TO GREEN BASIS %MC: In the ovendry basis method, as indicated prior, the %MC in the wood is expressed as a percentage of the dry weight of wood. As long as this dry basis MC is known, this is all that is needed to establish the equivalent green basis %MC, because the %MC on the dry basis is a surrogate for the weight of water and the ovendry weight would be equivalent to 100% (relative to the weight of water), therefore, to convert from OD basis %MC to Green basis %MC the calculation is as follows:

$$\text{MC\% (Green basis)} = \left(\frac{\text{MC \% (OD basis)}}{100\% + \text{MC\% (OD basis)}}\right) * 100$$

TO CONVERT GREEN BASIS %MC TO OVENDRY BASIS %MC: In the green basis method, as indicated prior, the %MC in the wood is expressed as a percentage of the total weight of dry wood plus water combined. As long as this green basis MC is known, this is all that is needed to establish the ovendry basis %MC, because the %MC on the green basis is a surrogate for the weight of water and the ovendry weight would be equivalent to subtracting this same % MC green basis from 100% to create a surrogate for the proportional dry weight, therefore, to convert from Green basis %MC to OD basis %MC the calculation is as follows:

$$\text{MC\% (OD basis)} = \left(\frac{\text{MC \% (Green basis)}}{100\% - \text{MC\% (Green basis)}}\right) * 100$$

It should be noted that in each case the conversion is simply accomplished by an appropriate adjustment to the denominator in the equation. This is very simple with a little practice.

Common methods of moisture content determination and what is most suitable for woody biomass of various types

There are several common ways in which the moisture content percentage of wood is routinely estimated. All of these have a purpose and place and there are often practical reasons (cost, convenience, time, practicality, etc.) that a given method of estimating moisture content may have an advantage over other methods. The precision level for the methods that are commonly used to estimate moisture content of woody biomass should not be assumed to be any greater than to the integer level (i.e. to the nearest 1%) and with a precision level of from +/- 1%, so calculated moisture contents should be rounded to the nearest integer value (i.e. the calculation should be rounded to the nearest 1%)

The oven-drying method

Overview of the oven-drying method: The primary oven-drying method (this is "Method A – Oven-Drying Primary" as detailed in ASTM D4442-07) is intended as the sole primary method and is structured for research purposes where the highest accuracy or degree of precision is needed and requires a specific oven type (i.e. a vented forced convection oven), closed weighing jars, and the performance of additional special procedures. **The oven-drying method most practically suited for use in determining the moisture content of wood biomass that is typically or most commonly in the forest industry is often simply referred to by most people in forest industry as "the oven-drying method" (this is actually "Method B – Oven-Drying Secondary" and is also detailed in ASTM D4442-07 which provides detail regarding calibration and standardization details for both methods).** This oven-drying method is appropriate for use with woody biomass samples regardless of moisture content, and although it takes some time to complete the test (usually about 24 hours, and possibly more), the time spent in dealing with each of the individual samples is minimal, and given a large

drying oven, a fairly large number of samples can be handled at one time. For these reasons, the oven-drying method is the method that is most commonly used, and other methods (while also suitable) are typically compared to the results of the oven-drying method to ensure their accuracy.

The oven-drying method procedures: The oven being used must be capable of maintaining temperatures of 103°C +/- 2°C (or holding between 101°C to 105°C) near the drying endpoint (this is the same as holding between about 214°F and 221°F). The sensitivity of the balance (scale) that is being used to weigh the samples must be to within a minimum of 0.1% of the weight of the sample being tested (for example, if samples being tested are expected to be about 100 grams in weight when dry, the scale should be able to read to at least 0.1 gram (or a tenth of a gram) – this would be the minimum sensitivity allowable, but a somewhat greater sensitivity, such as a sensitivity of 0.01 gram (or a hundredth of a gram) would be preferred in this situation. Samples collected for moisture content determination are to be kept in individual vapor-tight containers if there is any delay between the collection of the sample and the initial weighing which will determine the "green weight" that is the weight of wood and water combined. (Note: If the sample is placed, kept and weighed in a container, such as a small aluminum pan typically used to hold chips or sawdust in drying ovens, the weight of the empty pan needs to be known and subtracted from all numbers in the calculation, or else the balance needs to be tare weighted to eliminate the pan's weight from what is recorded with each weighing.) After initial weighing, the sample is placed in the oven and kept there until the endpoint has been reached and is then removed and reweighed as soon as possible. It is known that the endpoint is reached when there is no appreciable change in the final weight at approximately 4 hour intervals. The weight of the sample at endpoint is a direct measurement of the dry weight of wood in the sample, which is subtracted from the green weight of the sample (from the initial weighing) to calculate the weight of water. The weight of water is then divided by the green weight of the sample (from the initial weighing) to calculate the Green basis moisture content of the sample (round to the nearest 1%).

In most cases the oven-drying method can be completed in about 24 hours of testing, assuming the materials contained in the samples being tested are not very large in size (e.g. in testing samples of chips and smaller material, these samples can typically be processed within a 24 hour period in a good forced-convection oven that is properly vented and is not overloaded). If relatively large sizes of material are included as part of the samples being tested, or if a very large volume of high-moisture material is placed in the oven at one time, this can result in the samples requiring a longer time in the oven to reach endpoint. In using an oven in testing various types of samples over time, an operator who has appropriately tested for endpoints when running samples of various types and moistures (and with various loads in the oven and during various climatic conditions) could typically be expected to reasonably estimate the time to endpoint for the samples being tested relative to the conditions at hand. It should be obvious that it is important to get the samples to endpoint in using the oven-drying method of moisture calculation or the recorded dry weight for the sample will be overstated (i.e. what is recorded as dry weight of wood will be too high as it will have a residual water fraction) and consequently the resulting moisture content calculation will then understate the moisture content (i.e. the calculated moisture content from the test will be less than the actual moisture content of the sample). In the circumstance where woody biomass is purchased on a dry ton basis, this failure to reach endpoint in drying of samples and resulting understatement of moisture content will overstate the dry tons of material actually received by the purchaser and will result in an overpayment to the supplier – consequently it is not an error a purchaser can afford to make in a significant way on a regular basis. For this reason it is important for the purchaser to use good procedures and to ensure the samples being tested reach endpoint.

Determining moisture content using a microwave oven

Overview of determining moisture content using a microwave oven: A microwave oven may be used in determining the moisture content of particulate wood (as detailed in ASTM E1358-97), such as would be represented in many forms of woody biomass samples being tested for moisture content. The advantage of the procedure in using a microwave oven is that the test is relatively quick, typically requiring only about ten to fifteen minutes to perform. This aspect of timely results is generally what makes the procedure appear to be an attractive option. The negatives associated with the procedure are what generally reduce it to being a procedure more suited for occasional versus primary use in the eyes of most potential users. Two minor negatives to the procedure is that for all practical purposes only one sample may be tested in the oven at any given time, and that the testing of the sample needs to be closely monitored. A major negative to using the procedure is the risk of combustion of the sample during testing which is at least in part why the ASTM E1358-97 standard indicates: "*This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*" **Where a microwave oven is to be used in determining the moisture content of wood it is essential to have a plan and appropriate mechanisms and materials to deal with the fires that will occur with testing.**

Procedures for determining moisture content using a microwave oven: The microwave oven to be used can be any standard commercial microwave oven that has a power output of at least 600 W. The sample size to be tested is to be approximately 50 grams, so the sensitivity of the balance (scale) that is being used to weigh the samples should have a minimum sensitivity of 0.01 gram (or a hundredth of a gram). The approximately 50 g sample of the wood to be tested is placed on 3 sheets of standard paper towels placed on top of each other, the weight of which (towels) has been recorded. The sample with the towels is weighed, the sample (on the towels) is then placed in the oven and is heated on full power for a heating interval, it is then removed from the oven after the heating interval, reweighed and stirred and returned to the oven for another heating interval. This is continued until endpoint, where the weight change after a drying interval is less than 0.5 g. The weight of the sample minus the weight of the towels (recorded prior) is the dry weight of wood for the calculation, and the weight of the original sample and towels minus the weight of the towels is the green weight of the sample for the moisture content calculation.

An appropriate schedule of intervals of heating times (after which the sample should be reweighed and stirred before further heating) for higher moisture mixed woody biomass in particulate form would be something on the order of a first heating interval of 2 minutes, followed by two 1 minute intervals and then 30 second intervals thereafter. For lower moisture material (such as woody biomass well seasoned prior to chipping) it would be recommended to use a process cycle of three 1 minute intervals and then 30 second intervals thereafter. For drier materials still, a process cycle of two 1 minute intervals and then 30 second intervals thereafter would be more appropriate. The short intervals of heating times are very important to ensure that the sample is not overdried. When in doubt, shorter intervals are preferred.

If material larger in size than normal chips or hogged fuel is included in the sample this does not simplify the situation, rather an even greater care must be exercised. Continuing the microwave heating of larger pieces of wood for too long will easily result in the sample starting on fire, and it will typically burn from the inside of the piece giving little early visual indication of combustion (and perhaps no obvious indication of combustion on the surface, but on cutting the piece a charred center would be obvious). For this

reason, using a microwave in moisture content determination of larger samples (such as rounds cut from logs or large materials from a grinder) is not recommended. It is difficult for most people to believe how easy it is to have a sample of wood start on fire by overheating it in the microwave until they experience it themselves in testing, but the wood will catch fire if it is heated in the microwave long enough. The first indication of combustion is usually smelling smoke and then realizing that what appeared to be water vapor or steam leaving the piece was actually smoke. Pouring water on a larger sample will not likely immediately extinguish the fire as it will almost certainly be burning in the center, so for safety sake it is desirable to have a container of water that is large enough to easily hold the sample, and a means of holding it under the surface of the water is also desirable. (The sample could also be tossed outside if safe to do so – it will produce smoke for a long time.)

Determining moisture content of chemically treated biomass

Overview of determining moisture content of treated material: Although the oven-drying method is generally considered the standard to which other methods should be compared – none of oven-drying methods of any kind (including Method A – Oven-Drying Primary" as detailed in ASTM D4442-07, Method B – Oven-Drying Secondary" as also detailed in ASTM D4442-07, or the practice of moisture content determination using a microwave oven, as detailed in ASTM E1358-97) are appropriate for use with any material that may have been chemically treated or impregnated. Any kind of an oven-drying procedure (conventional or microwave) may produce incorrect results in estimation of moisture content (beyond an acceptable margin of error) due to the potential concomitant removal of the treatment carrier (and/or chemical itself) along with the moisture, resulting in an overestimation of moisture. More importantly such a practice should be considered inherently dangerous due to increased potential for increased safety risks related to fire or explosion, and for health risks related to the potential for respiratory and other related exposure to chemicals in the sample being handled and volatilized in the drying process. **DO NOT USE AN OVEN-DRYING METHOD OF ANY KIND TO DETERMINE MOISTURE CONTENT OF CHEMICALLY TREATED OR IMPREGNATED MATERIAL.** Combustion of chemically treated materials can have special problems or concerns, such as those related to stack emissions and ash disposal, and should not be undertaken without appropriate planning. Consideration regarding the moisture content determination of chemically treated biomass is just one aspect of a large potential problem that needs to be carefully considered before opportunities to use treated biomass can be exploited.

Procedures for determining moisture content of treated material: The Distillation method ("this is Method C - Distillation (secondary) method —as detailed in ASTM D4442-07) is the appropriate method of determining the moisture content of chemically treated or impregnated material. This procedure requires special laboratory equipment and some basic level of knowledge and expertise related to chemistry lab practices. The detailed discussion of this method is beyond the scope of this paper.

Determining moisture content using an electric moisture meter

Overview of determining moisture content using an electric moisture meter: Electric moisture meters may be used in determining the moisture content of woody biomass in certain circumstances, but such use is inappropriate in other circumstances. Electric moisture meters are reasonably priced, portable, quick and easy to use, and already have widespread use in the forest industry and the building trades. Most people are more familiar with hand-held versions of these meters, but there are also stationary versions of these meters that can monitor material on a conveyor (and are often used to monitor veneer or lumber in manufacturing). Almost all of the hand-held electric moisture meters readily available are

conductance type meters which are able to operate using the relationship between moisture content and direct current conductance where direct current conductance increases with moisture content. (These are also sometimes called "resistance type" meters – resistance being the reciprocal of conductance.) There are also other types of moisture meters that use the relationship between moisture content and the dielectric loss factor of the wood (sometimes called the "power-loss type") or which use the relationship between moisture content and the dielectric constant of the (sometimes called the "capacitance type"). The publication "Electric Moisture Meters for Wood" (USDA - Forest Service Forest Products Laboratory General Technical Report FPL-GTR-6) by William James provides excellent information on the performance and limitations of these devices. The key element of concern for use of electric moisture meters with woody biomass is related to the moisture content of the piece being tested needing to be within the moisture content range at which the device may be reasonably expected to give a reasonably accurate reading.

Procedures for determining moisture content using an electric moisture meter: Since manufacturers of stationary meters would establish the appropriate procedures and parameters for use of their equipment, this discussion is more specific to hand-held devices. Hand-held pin type moisture meters are useful for determining moisture content of some forms of woody biomass, such as edgings, slabs, scrap lumber and similar materials within appropriate moisture contents, and specialized hand-held meters are also made for sampling fine woody biomass (such as sawdust) also within appropriate moisture content ranges. Moisture meters are generally suited to giving quantitative measures of moisture content between about 7% and 30% MC on the ovendry basis (or about 6% to about 23% on the green basis). Most pin type meters readily available in the U.S. market indicate moisture content on the ovendry basis, but it is important to verify the basis (i.e. ovendry or green) on which the device you use is indicating moisture content. For higher moistures (i.e. anything above about 30% MC on the ovendry basis) a conductance type device may be expected to provide a qualitative indication of high moisture but the quantitative reading indicated cannot usually be trusted – what this means is, just because the meter might indicate 40% or 50% or 60% MC, doesn't really mean anything except that the piece is significantly above 30% MC. It must be understood that just because a meter gives an indication above 30% MC on the ovendry basis does not mean the meter is accurate at that reading (assume it is not). In a similar way, do not expect explicit accuracy for readings below about 6% or 7% MC on the ovendry basis.

Temperature, moisture distribution and species affect the accuracy of readings for the meters, along with other factors. Temperature correction is actually a function of both moisture content and temperature, so a supplier provided correction table is preferred, but as a rule of thumb, you can correct the reading by subtracting 1 % MC for every 20°F above the calibration temperature and adding 1 % MC for every 20°F below the calibration temperature for (the most common) conductance type meters. Some meters have correction buttons for use of the meter with different species, while others may have correction tables (corrections are usually less than 2% for U.S. species). Uneven moisture distributions can also give readings that will deviate from a true average (usually overestimating by reading along the lines of higher moisture).

For determining moisture content of some types of solid woody biomass (such as partially dried slabs, edgings, etc.) the common, inexpensive hand-held pin-type electric (conductance) moisture meters are useful tools that should be on hand. Also, some of the newer meters that sample sawdust and other small particle residues are worth consideration of having on hand for anyone who purchases fine woody biomass residues that are below fiber saturation point of about 30% MC on the ovendry basis. These devices for particle materials generally work by a conductance measurement of a small sample of sawdust or other fine material that has been compressed to a

constant pressure of about 0.2 MPa. In using a pin type meter, it is desirable to have the pins oriented along the grain versus across the grain as a general practice (and this is more important as moisture contents increase towards the higher end of the working range – where failure to do this can result in lower than actual readings). Chemical treatments and glues can lead to inaccurate readings (usually higher than actual). Using a pin type meter, the pins should be inserted in the piece to a depth of about one fifth to one fourth of the thickness of the piece of wood being measured, and where there is significant variability expected in the piece (e.g. due to rapid drying from the ends) it would be advisable for multiple reading to be made on the piece being sampled.

Determining moisture content using specialized devices

Overview of determining moisture content using specialized devices: Commercially produced bench-top devices are made for the express purpose of moisture measurement of wood or woody biomass. Usually these devices require a small sample that is tested in a process by the machine with the moisture content directly indicated. Different types of these devices have existed for a long time, and it is safe to assume that new products will continue to be developed. These are generally well suited to purposes where very small samples are acceptable and the results are required fairly quickly, and where running one sample at a time is practical. Many people like these devices and are satisfied with the price paid, the results obtained, and the volume of material they can handle – while other people prefer the more conventional tools and practices. These specialized devices are something that for some people may be worth examining – where that is the case it would probably be prudent to carefully examine what is available on the market, and if possible to try to talk to people who use the equipment and to understand how they use the equipment in terms of type of materials tested and number of samples tested in a day.

Sampling practices suitable for use with woody biomass of various types

Overview of sampling practices for moisture content determination of woody biomass: The sampling practices and the sample selection processes to be used to determine the moisture contents of woody biomass of various types, being delivered by various suppliers, from various locations, at different times of the years is something which deserves considerable thought and planning, with regard to how the samples will be collected, labeled, stored and processed, and also what should be the required frequency of sampling. In doing this, the practical aspects of sampling that must be considered would include safety considerations, the form of the material as received, if the material will be immediately staged for use as received, or stored for drying (such as being held for drying in roundwood form prior to use), the volume of material coming from various suppliers, the variability regarding moisture content for the material being received from the various suppliers, and the physical constraints and the costs of testing samples need to be considered at a minimum.

First and foremost – it must be remembered that consideration of human safety is the most important consideration in developing sampling and testing practices. No woody biomass sample is worth anyone risking significant injury or death in sample collection or processing. Each circumstance is somewhat different, so each place of work must be carefully evaluated with an eye toward safety in developing sampling and testing practices. Particular concern should be given to developing practices that eliminate or at least greatly minimize the possibilities of serious injury or death, such as anyone being crushed or struck or by machine or material movement, and the risk of falling off of loads or piles. In the testing of material, particular concern should be given to proper venting of volatiles released from samples in drying ovens, prohibition of oven-drying test method of treated and/or contaminated materials and an eye towards fire safety.

With regard to the frequency of sampling from various suppliers, consideration must be given to the costs associated with sampling and testing overall, the variability expected in the moisture content of material being received from various suppliers (at any particular point in time and over time), and physical constraints associated with sampling collection and processing, as well as having an eye towards overall costs and efficiency in the overall sampling process.

Sampling practices for woody biomass in particle form – for oven-drying testing: In sampling most woody biomass in particle form (such as chips and sawdust); a sample volume that is roughly twice the desired average weight at endpoint is generally appropriate. For example, assuming a dry sample size of approximately 100 grams is desired for oven testing; an appropriate green sample of about 200 grams (slightly less than half a pound) would be desirable in sampling high-moisture residues such as most woods residues. If material being tested is known to be at significantly lower moisture content, then a roughly equivalent volume of sample of similar type of particle material (having proportionately lower weight) would be appropriate for drier material. In practice it will quickly be recognized that samples should be large enough relative to the need for appropriate levels of precision in consideration of the equipment being used, however, overly large samples quickly take up the limited capacity of drying ovens. In a practical sense, the system for testing woody biomass in particle form needs to be considered on a holistic basis wherein the capacity of drying ovens available is sufficient to reasonably accommodate the material to be tested in a given time period, considering both the space required for the pans and the overall volume of material to be tested (and associated volume of water needing to be removed).

A sample selected to be tested in oven drying can be an individual sample selected specifically for that purpose, or can be obtained as a reduction from a gross sample (i.e. a sample from a gross sample) with that gross sample being simply a larger sample that is systematically collected over time. In terms of example, the sample to be tested may be a sample selected to represent the moisture content of a truckload of material from a supplier who occasionally delivers a truckload of biomass – or in contrast, for a major supplier, it may be desirable to collect a gross sample, wherein a sample from each truckload of material
delivered by that supplier from a particular job site may be collected and aggregated together in an airtight container as a gross sample, with the sample (or multiple samples) that is to be tested then being taken from the gross sample, and representing multiple truckloads for that job that are represented in the gross sample. Generally, the size of a gross sample should be fairly large, such as at least 10 kilograms (about 22 pounds) in green weight, and the removal or selection of the sample to be tested from the gross sample needs to follow an appropriate procedure (as detailed in ASTM E 871 – 82). The selection of the sample from the gross sample is most easily done by use of a riffle (such as a coal riffle) that progressively divides the gross sample into parts, from which one part is retained for further division, and that division continues until an appropriate size sample for testing remains. In terms of example, if a gross sample of about 10 kilograms in weight is progressively divided into halves, with one half retained for division and the other half discarded (e.g. with the first division by half of the 10 kilos of the gross sample, about 5 will remain; with the 5 kilos divided in half, about 2.5 kilos will remain, etc.), in about six divisions by half, you will end up with a sample of about 200 grams.

In a practical application, where the woody biomass material being tested is in the form of some types of forest residues that has been run through a tub grinder, there will likely be considerable variability in the size of the material delivered. In proper sampling this larger material will represent itself in the gross sample (note: you should not arbitrarily reject larger material from the sample or selectively chose material of a size desired). Where this is the case that you have larger material in the sample than the size of material that is desired for testing, from a

practical standpoint it may be desirable (if not necessary) to accomplish some gross reduction in the size of material in the sample (such as running it through a hammermill) at least prior to oven testing and it may be necessary to perform a reduction on the entire gross sample itself, or at some point fairly early in the division process if very large pieces of material could represent a problem in sample division. Very large pieces of material in the sample may not easily be accommodated in the drying pans and if they do, it is possible they may delay the sample reaching endpoint as they would not lose moisture as easily as smaller particles having greater surface area relative to their mass. If a microwave oven is being used in the testing, the particle size in the sample being tested would obviously become even more important, due to the differences in rate of drying and the smaller sample size, consequently it may be desirable to generally reduce microwave samples to a smaller size particle than typical for testing in a conventional oven.

As indicated prior, the material being collected for the gross sample needs to be held in an airtight container until the sample for testing is to be drawn from the gross sample. That sample for testing, and any individual samples selected from it for testing also need to be held in an airtight container of some type until their initial weighing in the testing process to determine green weight of the sample. If this is not done, the sample to be tested may be expected to lose moisture to the atmosphere, and this loss of moisture in the sample will result in the calculation of a moisture content that is lower than would accurately represent the load or loads being represented by that sample. (Or the reverse could occur if very dry material was being received and tested, but this is unlikely.) In a practical sense it will quickly be recognized that containers for the collection and storage of gross samples that could easily weigh more than 25 pounds could be any of a number of durable, larger airtight storage containers readily available from a variety of sources. For holding an individual sample for testing until it is ready to begin to be processed, both larger "zip-loc" type food storage bags and reusable small, durable air-tight containers work well.

The physical collection of woody biomass samples should be done by a regular process – which as noted prior – gives key concern to safety. The sample may be physically taken by hand or by some collection device (such as a small container on a pole), and the sample for a load may be taken from one or more parts of the load (depending on what may be practical or physically possible). Reasonable consideration should be given to not sampling primarily or solely from what would clearly be atypical for the load as a whole. For example, if biomass is transported in a truck with a rear screen on a rainy day or during a late or early snowfall, a very small layer of the load against that screen could pick up considerable moisture in the haul – and in a similar vein, a small portion of the load exposed by such a screen to hot, dry air could be expected to lose moisture in a long haul. In either case, although these extremes would indeed represent a very small part of the load, the extremes would not represent a reasonable average for the load from which the material was taken, if the extreme area of unusually higher or lower moisture was all that was selected from as a sample for the load. Where possible, sampling somewhere near the middle of the load as a regular practice should reasonably be expected to work best over time and to be most fair to both buyer and seller.

Sampling practices for woody biomass in solid form – oven-drying testing: The sampling of woody biomass in larger solid form – such as from cull logs – presents some special problems. Where the form of the biomass as received has each component element that is huge relative to the desired size of a sample for testing in oven-drying, so clearly it is not possible to simply take samples by hand from the material received. To accomplish appropriate sampling of such material in the woods can be a relatively easy but time consuming process, wherein from a selected representative sample tree at the time of harvest, thin disks of uniform thickness (e.g. about one inch in thickness) may be cut from the stem as each bolt or log is bucked from the tree, such that the disks considered in total would provide a sample giving a weighted average for the stem as a whole, and the sample could be tested in its entirety (or each disk

could be reduced by hand with a proportional pie-cut fraction retained, such as retaining a disk equal to a pie cut from outer surface to center, of equal proportion, such as a half, or a quarter, and that sample could be tested in its entirety), or the sample of disks could become a gross sample that could be reduced in a hammermill and then reduced in a riffle to provide a smaller sample for testing.

However, in normal circumstances where such cull logs are received on a truck with no real opportunity to sample at the point of harvest, the possibility of maintaining the integrity of sample trees is lost. Disk collection from a sample of logs could still be an acceptable mechanism for collection of a gross sample; however, there is a problem with cutting disks from woody biomass logs or boltwood as received for moisture content sampling. Once cut into logs or bolts, the logs will rapidly begin to dry longitudinally (from the ends), such that the wood at the ends would typically be at a lower moisture content than would be typical or average for the log. Cutting a disk from near the middle of the log would be expected to be a much better representation of the average moisture content for the log – and this would be a good testing practice if it is practical – but in many cases this will not be practical. Increasingly some purchasers of woody biomass in roundwood form are purchasing the material and holding it for seasoning for a significant time (in many cases from six months to a year) in an effort to reduce moisture content of the material. In this circumstance in particular, and in other circumstances as well, bucking bolts or logs to retrieve sample disks for moisture measurement is not a practical alternative due to problems it will create further handling and storage of the logs.

Sampling from near the (longitudinal) center of logs or bolts using an increment borer is a practical alternative to the cutting of sample disks. The appropriate procedure for such sampling on a log would be to place the borer perpendicular to an imaginary plane on the tangential face of the log and bore to the center of the log (i.e. to the pith). The problem in such a sampling procedure is that the small cylinder of wood removed is of equal diameter throughout (i.e. from the bark surface to the pith), and the sampling as such would tend to greatly over-sample the center half of the log (nearer the pith) and to under-sample the outer area of the log, relative to the proportional volumes of these areas. Given the expectation of typical differences in the moisture content of heartwood versus sapwood, and also a significant understatement of the bark fraction in sampling, this creates some significant problems. A very simple solution to this is that in addition to taking the initial sample bore from bark surface to the pith (half the diameter or the radius) on a given log, two additional sample cores are then taken in the same approximate location and in the same way, except in taking those two additional cores, they are taken to a depth of only one half of the depth of the initial sample. This would entail taking a total of three cores in total from one general location (near the longitudinal center) on a given log being tested – the first being one sample core all the way from the bark surface to the pith (half the diameter) and two additional cores in the same general location but only going to half the depth of the original (i.e. to only one-fourth of the diameter or half the radius). This is a slight additional effort but represents a much better overall sample because it makes an adjustment to better proportionately sample the log's volume in inner and outer fractions.

For an understanding of why this differential sampling is important, consider a circle of any diameter representing the cross-section of a log. Two parallel lines placed close together extending from the center of the circle to the perimeter could be used to represent a sample of the circle removed by an increment core. This type of sampling would equally represent the portions of the circle represented in the area contained in the inner half of the radius and the outer half of the radius, however, the actual area represented with the inner "half" of the circle in the form of a smaller circle with the same center and half the original radius would only represent about one-third of the volume contained in the outer "half" of the circle (which is represented as a ring around the

half-diameter circle). This would mean that about one fourth of the total area would be represented in the smaller (half-full diameter) inner circle, while about three fourths of the total area would be represented in the outside ring around that small circle, where the thickness of the ring is equal to half the radius of the larger circle and equal to the radius of the smaller circle. Essentially in using the increment core in the first extraction to the pith sample, half of the core will come from the inner circle and half from the outer ring – the two additional half-depth (or half full diameter) cores adjust the total sample to be representative of representing approximately three fourths of the total cores being taken from the outer "half" (outer ring) and one fourth from the inner "half" (half full diameter circle). The three cores are combined to form a sample for that log. In sampling a load, the three core sampling procedure may be applied to sampling multiple logs (taking three cores from each), with the sampling process mixing species and sizes as appropriate. All cores can then be combined to represent a sample for testing representing an individual load or used in developing a form of a "gross sample" of cores across a number of loads that may be used to collect a volume of material suitable to represent a lab sample (that could be tested in total without division by a riffle or other means).

The sampling of woody biomass in the form of asymmetrical high-moisture residual material (such as unseasoned slab wood or edgings obtained from small mills) presents some difficulties as compared to the testing of logs, as the three core procedure described for logs is not suited to this material being tested. This is because of the cross-section of these materials is not circular, rather it represent a fraction of a circle or an irregular shape. The problem is further exacerbated where the material may still be at quite a high moisture overall, but having a much greater surface area than is typical for logs, and some or all pieces of material may have had some seasoning processes begun (with associated loss of moisture) in short term storage and hauling. In sampling such materials, the use of an increment borer is still likely to be one of the best practical options, but the person taking the samples needs to be cognizant of the fact there is likely to be considerable variation in moisture content, that could be directly related to size (i.e. material with greater thickness in cross-section might be expected to have higher moisture content) , and also that there is likely to be a significant moisture profile in many pieces where the moisture content of the core may be expected to be significantly greater than the outer perimeter. Keeping these factors in mind can help underscore the need for selecting samples from a representative mix of materials in the load having different thicknesses and cross section. Also where these pieces would typically be fairly thin (compared to cull logs), sampling completely through the thickness of material may be a practical way of capturing a representative sample from pieces with a significant moisture profile.

Sampling practices for well-seasoned or dry woody biomass in solid form: In circumstances where woody biomass in solid form is delivered in a well-seasoned or dry condition, this permits the use of a simple hand-held pin-type electric (conductance) moisture meters to collect moisture measurements. This would be a realistic possibility where all (or virtually all) of the load could be expected to be at an average moisture content that is low enough to permit testing with an electric moisture meter. This is a reasonable and practical alternative where the moisture content of the material being received does not exceed about 23% MC on the Green basis (or about 30% MC on the OD basis). Such very low average moisture contents should almost never be expected for woody biomass in roundwood form, but can be quite common for woody biomass in the form of well-seasoned slabs and edgings from smaller sawmills (that could typically be at moisture contents close to the upper limit) and also in the form of dry solid wood residuals from secondary manufacturers that could be at quite low moisture contents (even possibly near the lower limit for accurate readings using such equipment). Where it is possible to use such a hand-held moisture meter for sampling an incoming load of material, it is a very quick and easy process to sample a number of pieces to estimate an average moisture content for the load,

sampling near the longitudinal center of the longer pieces, as with other processes, to limit the effect of excessive moisture loss from the ends. In the case of well-seasoned slabs at such low moisture contents, in many cases bark will have sloughed off or will be sloughing off, but where firmly fixed, both wood and bark should be sampled.

In sampling materials such as seasoned slabs and edgings that are likely at the upper end of moisture contents suitable for this process (e.g. well-seasoned slabs) if in about twenty to twenty five readings taken from different pieces yield no moisture readings so high that there is reason to mistrust any of the readings as being more likely reflective of a qualitative versus a quantitative nature, then an average of the readings may be used to represent an average for the load. If one or two of the readings taken indicate moistures somewhat above 23% MC on the Green basis (or about 30% MC on the OD basis), then additional readings should be taken (on additional pieces) to attempt to confirm that there is not too large a number higher-moisture pieces such that the use of a moisture meter for sampling may be inappropriate. As long as no more than 5 or 10% of pieces sampled reflect moisture contents above 23% MC on the Green basis, the average of all displayed moisture content readings should represent a suitable representative average for the load, however, if a significantly large number of pieces sampled are at a moisture where the reading is more qualitative versus quantitative, the average of the meter readings cannot be trusted to provide something that can confidently be projected as a true average for the load and testing better suited to higher moisture material (such as the oven-drying method) should be employed. In rare circumstances (usually in the winter) dry solid wood residuals received from secondary manufacturers could be at very low moisture contents such that for some pieces the readings reflect a moisture content of something less than 6% which is at the lower limit for accuracy in using a hand-held pin-type electric (conductance) moisture meters. Where that is the case, there is no particular problem in simply averaging the readings taken as the possible error introduced by inclusion of a few such readings is minimal where the range of difference between the true moisture content and the indicated moisture content on the meter is so small.

Sampling practices for well-seasoned or dry woody biomass in particle form: In circumstances where woody biomass in solid form is delivered in a dry condition in particle form (such as sawdust or other fine particles), that permits use of an inexpensive hand-held meter that can sample sawdust and other small particle residues this is likely to be the tool of choice for quickly sampling the occasional truckload of such material. Where larger suppliers might routinely ship truckloads of such material, it will probably be the case that the moisture contents of the material as received will be quite uniform, and the hand-held meter is simply used to confirm that knowledge. One or two samples of material per truckload delivered would be an appropriate sample in most cases. Any reading that indicates a moisture content that is above, at (or even very close to) the upper limit of the devices capability should be an indication that testing better suited to higher moisture material (such as the oven-drying method) should be used for the material.

Moisture content of wood in equilibrium with stated temperature and relative humidity (on the OVENDRY basis)

Temperature		Moisture content (%) on the OVENDRY basis at various relative humidity values												
°C	°F	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%
-1.1	30	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4
40	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	
10	50	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3
15.6	60	1.3	2.5	3.6	4.6	5.4	6.2	7	7.8	8.6	9.4	10.2	11.1	12.1
21.1	70	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11	12
26.7	80	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7
32.2	90	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5
37.8	100	1.2	2.3	3.3	4.2	5	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2
43.3	110	1.1	2.2	3.2	4	4.9	5.6	6.3	7	7.7	8.4	9.2	10	11
48.9	120	1.1	2.1	3	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6
54.4	130	1	2	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3
60	140	0.9	1.9	2.8	3.6	4.3	5	5.7	6.3	7	7.7	8.4	9.1	10
65.6	150	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7
71.1	160	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3
76.7	170	0.7	1.5	2.3	3	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9
82.2	180	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6
87.8	190	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5	5.5	6.1	6.8	7.5	8.2
93.3	200	0.5	1.1	1.7	2.4	3	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8
98.9	210	0.5	1	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6	6.7	7.4
104.4	220	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5	5.6	6.3	7
110	230	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6	6.7
115.6	240	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6		
121.1	250	0.2	0.4	0.7	1	1.3	1.7	2.1	2.5	2.9				
126.7	260	0.2	0.3	0.5	0.7	0.9	1.1	1.4						
132.2	270	0.1	0.1	0.2	0.3	0.4	0.4							

from table 3-4 of the USDA Wood Handbook - reprinted with permission

70%	75%	80%	85%	90%	95%
13.5	14.9	16.5	18.5	21	24.3
13.5	14.9	16.5	18.5	21	24.3
13.4	14.8	16.4	18.4	20.9	24.3
13.3	14.6	16.2	18.2	20.7	24.1
13.1	14.4	16	17.9	20.5	23.9
12.9	14.2	15.7	17.7	20.2	23.6
12.6	13.9	15.4	17.3	19.8	23.3
12.3	13.6	15.1	17	19.5	22.9
12	13.2	14.7	16.6	19.1	22.4
11.7	12.9	14.4	16.2	18.6	22
11.3	12.5	14	15.8	18.2	21.5
11	12.1	13.6	15.3	17.7	21
10.6	11.8	13.1	14.9	17.2	20.4
10.3	11.4	12.7	14.4	16.7	19.9
9.9	11	12.3	14	16.2	19.3
9.5	10.5	11.8	13.5	15.7	18.7
9.1	10.1	11.4	13	15.1	18.1
8.7	9.7	10.9	12.5	14.6	17.5
8.3	9.2	10.4	12	14	16.9
7.8	8.8	9.9			

°C	°F
-1.1	**30**
4.4	**40**
10	**50**
15.6	**60**
26.7	**80**
32.2	**90**
37.8	**100**
43.3	**110**
48.9	**120**
54.4	**130**
60	**140**
65.6	**150**
71.1	**160**
76.7	**170**
82.2	**180**
87.8	**190**
93.3	**200**
98.9	**210**
104.4	**220**
110	**230**
115.6	**240**
121.1	**250**
126.7	**260**
132.2	**270**

An illustration of species variation in average wood moisture content for selected Wisconsin species

Average moisture content % (ovendry basis) of green wood, for selected Wisconsin species

Hardwoods

Species	Heartwood	Sapwood
Apple	81	74
Ash, black	95	—
Ash, green	—	58
Ash, white	46	44
Aspen	95	113
Basswood, American	81	133
Beech, American	55	72
Birch, paper	89	72
Birch, yellow	74	72
Cherry, black	58	—
Chestnut, American	120	—
Cottonwood	162	146
Elm, American	95	92
Elm, rock	44	57
Hackberry	61	65
Hickory, bitternut	80	54
Hickory, mockernut	70	52
Hickory, pignut	71	49
Maple, silver	58	97
Maple, sugar	65	72
Oak, northern red	80	69
Oak, white	64	78
Walnut, black 90 73		

Softwoods

Cedar, eastern red	33	—
Fir, balsam	88	173
Hemlock, eastern	97	119
Pine, red	32	134
Spruce, black	52	113
Tamarack	49	—

from USDA Wood Handbook Table 3-3, with permission

Scott Bowe
Associate Professor & Wood Products Specialist
Department of Forest and Wildlife Ecology
University of Wisconsin
226 Russell Laboratories
1630 Linden Drive
Madison, WI 53706-1598
Phone: 608-265-5849
Fax: 608-262-9922
Email: sbowe@wisc.edu

Robert Govett
Professor
College of Natural Resources,
University of Wisconsin-Stevens Point
Stevens Point, WI 54481
Phone: 715-346-4212
Fax: 715-346-4821
Email: rgovett@uwsp.edu

Terry Mace
Forest Utilization and Marketing Specialist
Division of Forestry
Wisconsin Department of Natural Resources
One Gifford Pinchot Drive
Madison, WI 53726-2398
Phone: 608-231-9333
Fax: 608-231-9592
Email: terry.mace@wisconsin.gov

October 2010

Graphic Design and Layout by:
Heather Mace
Email: macehc5@yahoo.com