Wood Combustion Basics

Topics

Wood Composition

Combustion Process

Moisture Content and Seasoning

Questions ?

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Wood Composition

All wood is made up of primarily Cellulose, Hemi-Cellulose and Lignin.

Cellulose – $(C_6H_{10}O_5)_x$

Hemi-Cellulose –xylose, mannose, galactose, rhamnose, and arabinose (sugars).

Lignin - $C_9H_{10}O_2$, $C_{10}H_{12}O_3$, $C_{11}H_{14}O_4$

These are all essentially complex hydrocarbons which form chains and fibers with lignin acting as an adhesive binding it all together.

Common Name	Cellulose	Hemi-Cellulous	Lignin	Other
Softwoods	42.2	28	24-35	Ca 0-1
Hardwoods	42.2	38	15-20	Ca 0-1

Wood Composition

All common wood is made up of roughly 50 ±3% Carbon 6 ±1% Hydrogen and 44±3% Oxygen with the rest inorganic ash. Softwoods tend toward higher Carbon and lower Oxygen content than hardwoods.

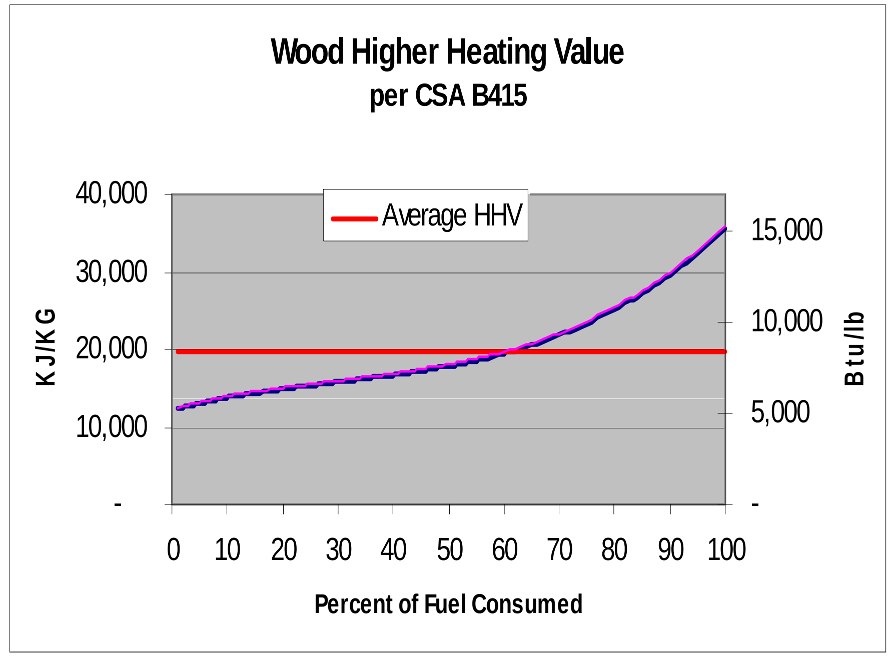
When burned completely about ½ the wood mass is converted to Carbon Dioxide and about ½ to water.

This process liberates about 8600 Btu's per pound (20 MJ/kg) of heat energy for hardwoods and 9000 Btu/lb (21 MJ/kg) for softwoods.

This is essentially the same amount of energy the tree soaked up from the sun when it created a pound wood.

Wood Combustion Basics

- Wood is a complex fuel that undergoes dramatic changes as it burns.
- When heated to 500-600 °F, wood undergoes pyrolysis which liberates organic gases and leaves behind carbon rich charcoal.
- Pyrolysis is an exothermic reaction and tends to be self sustaining once started.



Wood Combustion Basics

Up to 85% of the mass and 60% of the heating value from wood is contained in gases produced by pyrolysis.

Smoke and creosote represent unburned fuel.

Creosote is the condensed portion of smoke.

Smoke contains over 100 chemical compounds including CO, CH_4, and many hydrocarbons. All can be burned.

Primary and Secondary Combustion

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"Primary Combustion" is the burning of solid material directly. In wood combustion this is the burning of the charcoal – "hot coals", "embers".

"Secondary Combustion" is the burning of gas fuels which produces the flames of a fire.

Do not confuse with Primary and Secondary air as these terms are used with gas appliances.

Complete Combustion

Complete combustion of wood produces only Carbon Dioxide (CO_2) and Water (H_2O).

No visible smoke, no creosote, no harmful emissions.

Releases the full heating potential of the fuel.

Natural wood has no significant sulfur or metals content.

Incomplete Combustion

Incomplete combustion results in production of significant levels of CO, and many hydrocarbons.

These unburned components represent lost heating value, pollutant emissions and potential creosote formation.

Wood Combustion Basics

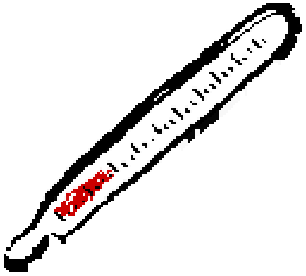
Complete combustion requires adequate oxygen and “the 3 T’s”.

- TIME
- TEMPERATURE
- TURBULENCE

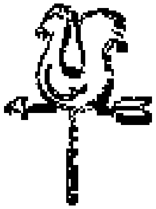
The 3 T's

- TIME - Sufficient time at the right conditions for combustion reactions to go to completion.

•TEMPERATURE - High enough temperature for fuel gas mixture to ignite.



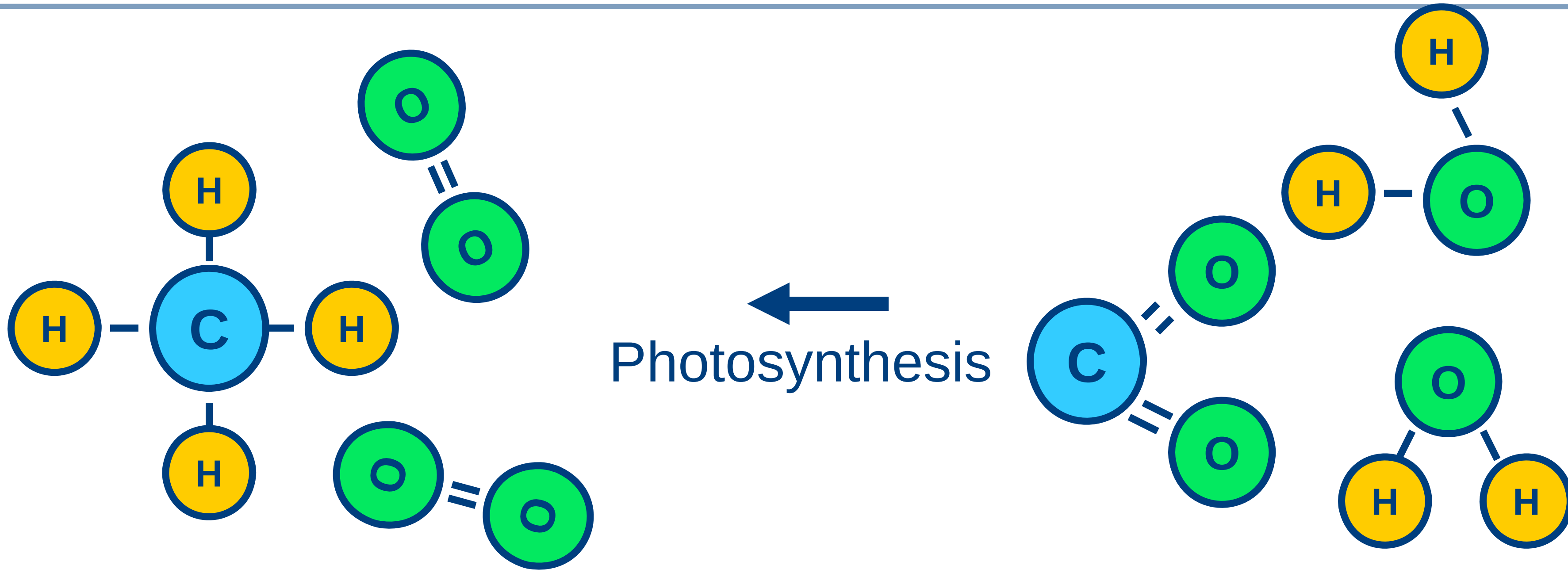
•TURBULENCE - To mix combustible gases with oxygen.



Conditions for Good Wood Combustion

- Temperatures in the 1100 to 1500°F range.
- Air/Fuel ratio of 10 to 12 pounds of air per pound of fuel.
- Residence time of 2-4 seconds in high temperature zone.
- No flame contact with “cold” surfaces that quench the flame and stop combustion.

Combustion Chemistry



+ HEAT

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O + \varepsilon$$

Wood Combustion Formula

$$\alpha C_A H_B O_C + uO_2 + hN_2 \Rightarrow \mathbf{d}CO_2 + hN_2 + jH_2O$$

"Stoichiometric" (ideal) Combustion:

1 lb of dry wood + 6.4 lb air ⇨ 1.83 lb CO_2 + 0.52 lb H_2O + 5.05 lb N_2

Of course, we never achieve ideal combustion. We always need significant "excess air" to approach 100% combustion. Usually 50 to 100% excess air is required. And we never actually get 100% Combustion. So the real chemistry looks more like this.

$$\alpha C_A H_B O_C + uO_2 + hN_2 \Rightarrow \mathbf{d}CO_2 + \mathbf{e}CO + \mathbf{g}O_2 + hN_2 + jH_2O + kC_X H_Y$$

MOISTURE CONTENT

Moisture Content refers to water that is contained within a piece of wood, but in not part of the wood molecules. We often refer to it as “free water”.

+

Moisture content is expressed on either a wet basis or dry basis. This refers to whether the dry or wet weight of the wood is used as the denominator.

MC is determined by weighing the wood, drying it completely at ~220 ^{o}F and weighing again.

MC Dry = $100 \times (Wt_{wet} - Wt_{dry})/Wt_{dry}$

MC Wet = $100 \times (Wt_{wet} - Wt_{dry})/Wt_{wet}$

MOISTURE CONTENT

Example:

Wet Weight = 1.25 lbs

Dry Weight = 1.00 lbs

MC Dry = 100 x (1.25-1.00)/1.00 = 25%

MC Wet = 100 x (1.25 – 1.00)/1.25 = 20%

Note that “100% MC Dry” means 1 lb of water per 1 lb of dry wood. Same as 50% MC Wet.

A 5 pound piece of wood with a 25% MC(dry) contains a pint of “free” water.

Electronic Moisture Meters are calibrated to determine MC on a dry basis.

We will use “dry basis” Moisture Content in the remainder of this presentation.

Electronic Moisture Meters

Dry wood is a good insulator.

Water in wood is a good conductor.

Moisture meters measure the electrical resistance through a fixed distance which is inversely proportional to the moisture content.

There are two types of probes or pins – short uninsulated pins and longer insulated pins that can be driven deep into the wood.

Electronic Moisture Meters

Wood dries from the outside in.

During drying there will normally be a large difference between MC between outer layers and the center.

However, as MC approaches equilibrium, it becomes more uniform.

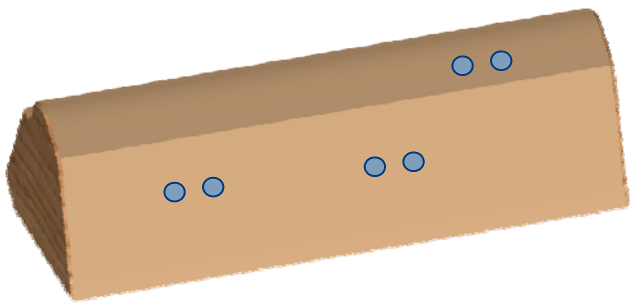
So for wetter wood the insulated type probe is needed to get an accurate measurement of MC. But for well seasoned wood the short probes are adequate.

Note: The short uninsulated probes read MC of the "wettest" area they contact – in normal conditions this will be at the tips.

Electronic Moisture Meters

In general readings taken at ¼ to 1/5 the wood thickness will be close to the average if the wood has had a month or two of drying time since cutting.

Take readings parallel to grain.



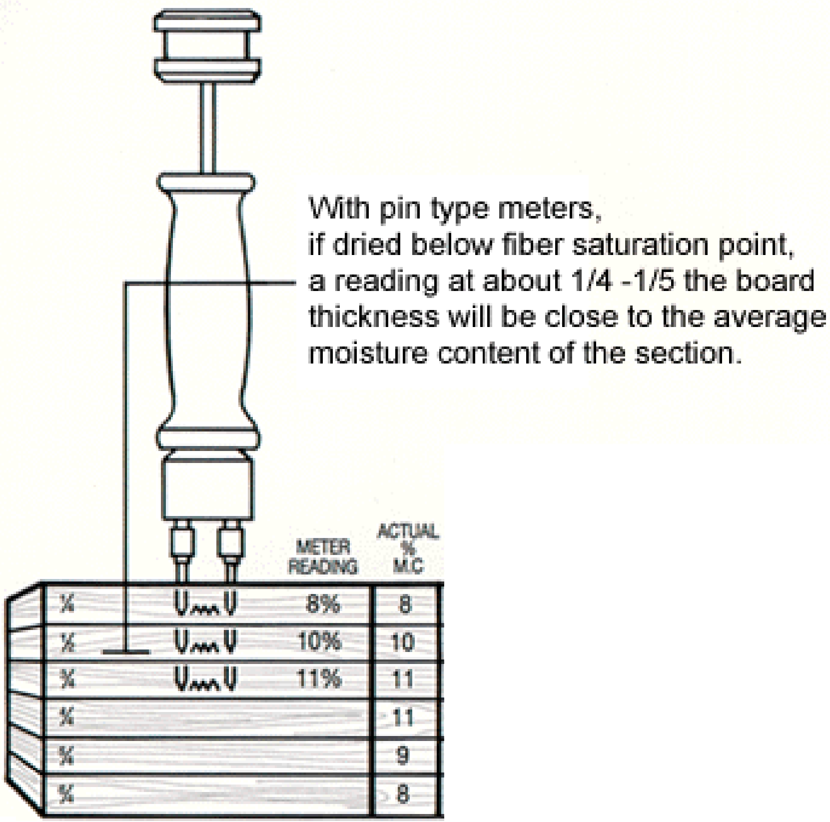


FIGURE I

PIN TYPE METERS
(HYPOTHETICAL DRAWING OF 6/4 BOARD WITH VARYING LEVELS OF MOISTURE.

Electronic Moisture Meters

Moisture meters are usually calibrated for Douglas Fir at 70 ºF.

Corrections are used for other species and temperatures.

Current popular models have built in species and temperature correction functions.

Moisture Contents above about 30 to 40% are in the fiber saturation range where the resistance is not significantly affected by increasing MC and thus are not accurately determined with a Moisture Meter.

MOISTURE CONTENT AFFECTS

Wood burning appliances are tested for emissions and efficiency performance with wood that is in a moisture content range of about 18 to 28% (15 to 22%wet basis).

This represents the normal range most people use most of the time – or at least what they should use.

Both higher or lower moisture content can have significant negative consequences.

High moisture reduces efficiency and makes it harder to start and sustain good secondary combustion. This is due to its cooling effect that slows down combustion and cools down the gases produced by pyrolysis.

Very dry wood tends to burn faster and can evolve gases at a rate that outstrips the appliance's ability to supply adequate air resulting in oxygen starvation. This can result in higher emissions, pulsating combustion and overheating.

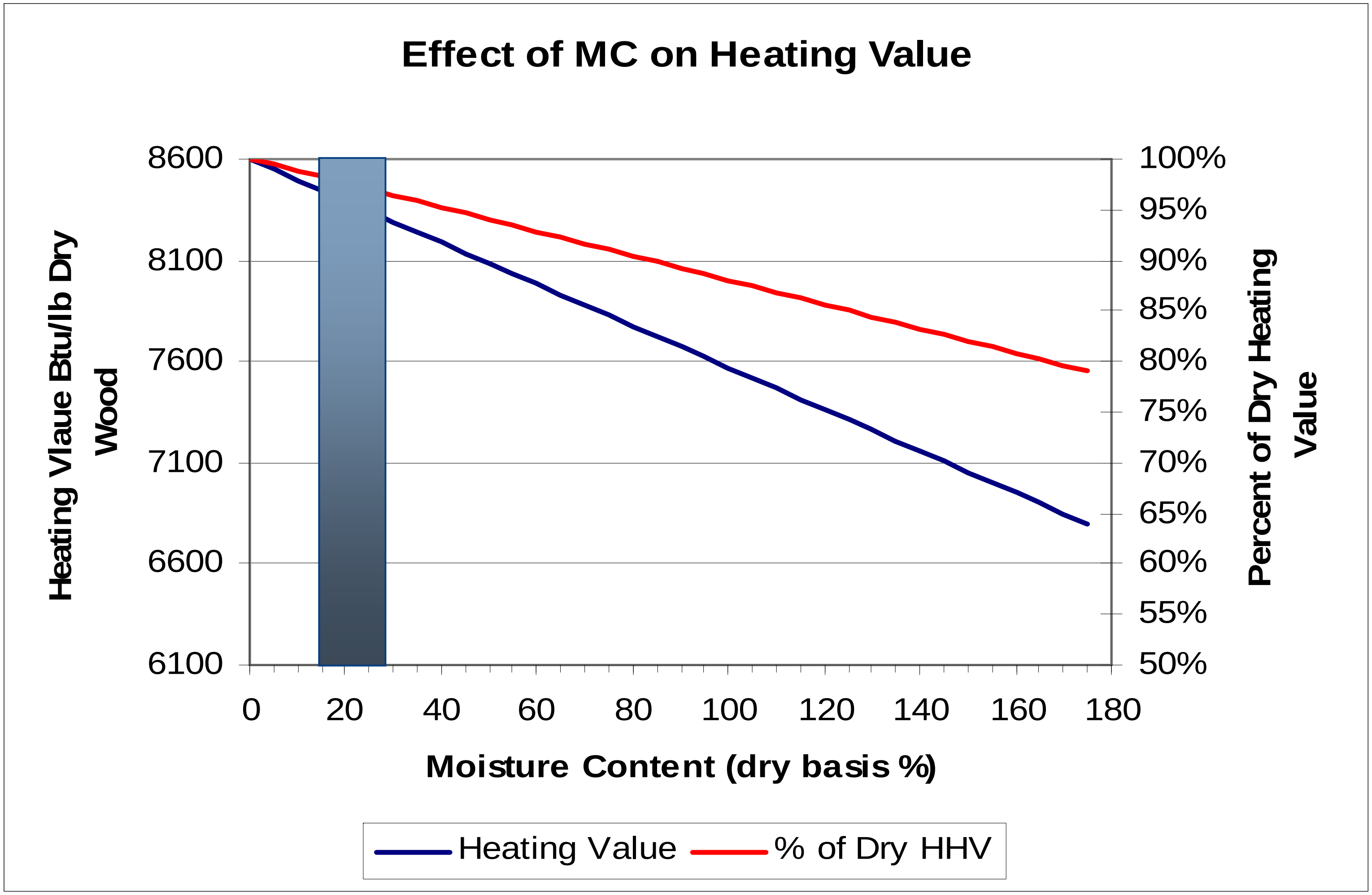
Fuel Wood Moisture

When wood is freshly cut it can have very high moisture content. Even trees that have been dead for years can have MC's as high as 50% or more. Living trees cut during the growing season can have MC's of over 150%

High moisture is not good for fuel wood.

- It soaks up heat to boil it off – Over 1030 Btu's per pound of water.
- It has a cooling effect on the combustible gases making it more difficult to burn them.
- It allows micro-organisms (mold and fungus) and insects to consume the wood.

Effective Heating Value v. MC



Drying Fuel Wood

To maximize heating efficiency and minimize poor combustion and emissions, it is essential to properly dry or "season" fuel wood.

Fortunately this is easily handled for us by time and mother nature.

The process requires little more than properly managing fuel supplies through cutting, splitting and storing to allow the wood to dry naturally.

Drying Fuel Wood

Wood will naturally dry to an “equilibrium moisture content” if it remains in a stable temperature and humidity environment long enough.

But “long enough” can be years and the environment that fuel wood is exposed to is far from stable.

Still, wood seasoning can be accomplished in less than a year if certain practices are followed.

Equilibrium MC

EMC Table											
Relative Humidity Percent	**Ambient Air Temperature - Degrees Fahrenheit**										
0	30	40	50	60	70	80	90	100	110	120	130
5	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1
10	2.6	2.6	2.6	2.5	2.5	2.4	2.3	2.3	2.2	2.1	2
15	3.7	3.7	3.6	3.6	3.5	3.5	3.4	3.3	3.2	3	2.9
20	4.6	4.6	4.6	4.6	4.5	4.4	4.3	4.2	3	3.9	3.7
25	5.5	5.5	5.5	5.4	5.4	5.3	5.1	5	4.9	4.7	4.5
30	6.3	6.3	6.3	6.2	6.2	6.1	5.9	5.8	5.6	5.4	5.2
35	7.1	7.1	7.1	7	6.9	6.8	6.7	6.5	6.3	6.1	5.9
40	7.9	7.9	7.9	7.8	7.7	7.6	7.4	7.2	7	6.8	6.6
45	8.7	8.7	8.7	8.6	8.5	8.3	8.1	7.9	7.7	7.5	7.2
50	9.5	9.5	9.5	9.4	9.2	9.1	8.9	8.7	8.4	8.2	7.9
55	10.4	10.4	10.3	10.2	10.1	9.9	9.7	9.5	9.2	8.9	8.7
60	11.3	11.3	11.2	11.1	11	10.8	10.5	10.3	10	9.7	9.4
65	12.4	12.3	12.3	12.1	12	11.7	11.5	11.2	11	10.6	10.3
70	13.5	13.5	13.4	13.3	13.1	12.9	12.6	12.3	12	11.7	11.3
75	14.9	14.9	14.8	14.6	14.4	14.2	13.9	13.6	13.2	12.9	12.5
80	16.5	16.5	16.4	16.2	16	15.7	15.4	15.1	14.7	14.4	14
85	18.5	18.5	18.4	18.2	17.9	17.7	17.3	17	16.6	16.2	15.8
90	21	21	20.9	20.7	20.5	20.2	19.8	19.5	19.1	18.6	18.2
95	24.3	24.3	24.3	24.1	23.9	23.6	23.3	22.9	22.4	22	21.5
98	26.9	26.9	26.9	26.8	26.6	26.3	26	25.6	25.2	24.7	24.2

Drying Fuel Wood

The goal of "seasoning" fuel wood should be to get it to a relatively uniform moisture content of 20 to 25%.

It helps to understand how wood dries when discussing what should be done to season fire wood.

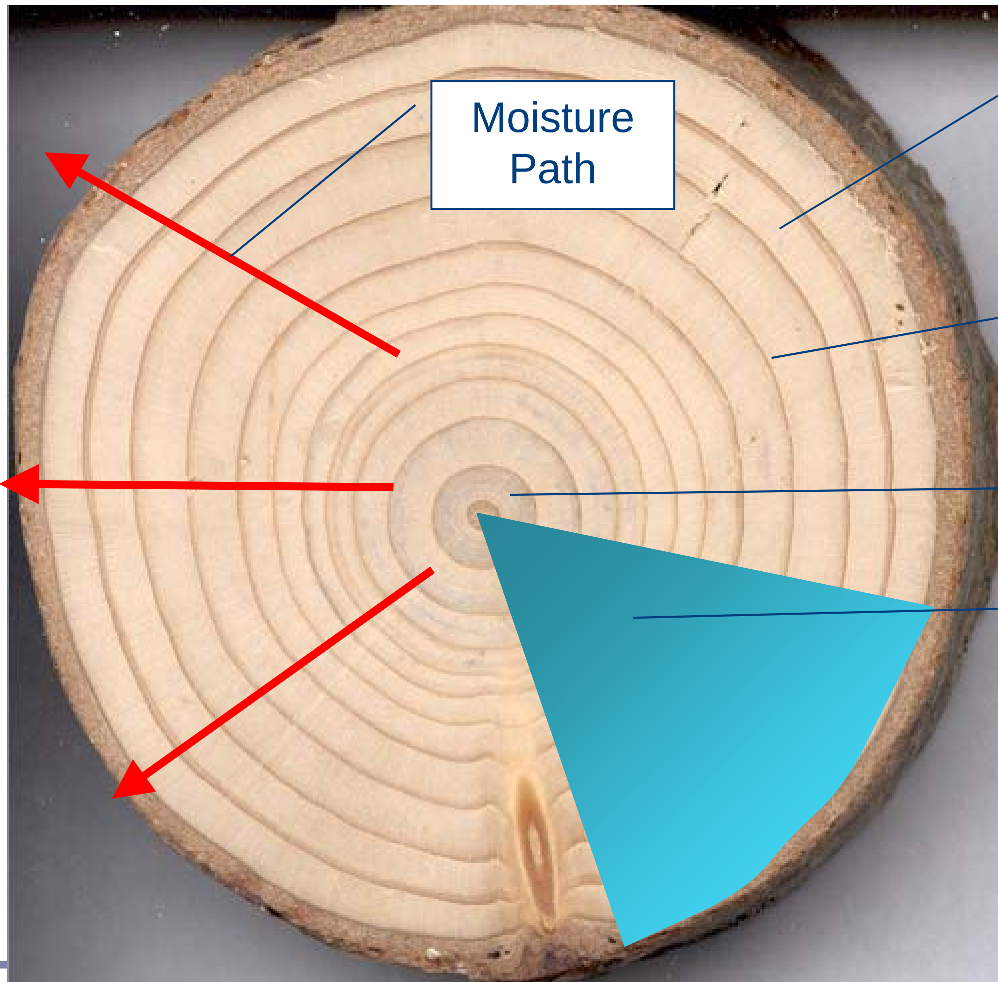
- Once a tree is cut, free water trapped in the structure will begin to work its way to the much lower humidity ambient environment.
- But the wood structure tends to make this moisture migration very slow.
- The easiest path for water to work its way out is through the ends of the log – i.e. moving parallel to the wood grain.

Drying Fuel Wood

- Drying out the ends essentially utilizes the same paths for water movement that the tree used to draw water from its roots when it was alive.
- But if the logs are long, the path is long and the process can be very slow. So cutting wood to short useable lengths right away helps speed the seasoning process.
- Still, it may take a long time for larger logs to dry down if left in full rounds.
- Splitting fuel wood can substantially reduce drying times.

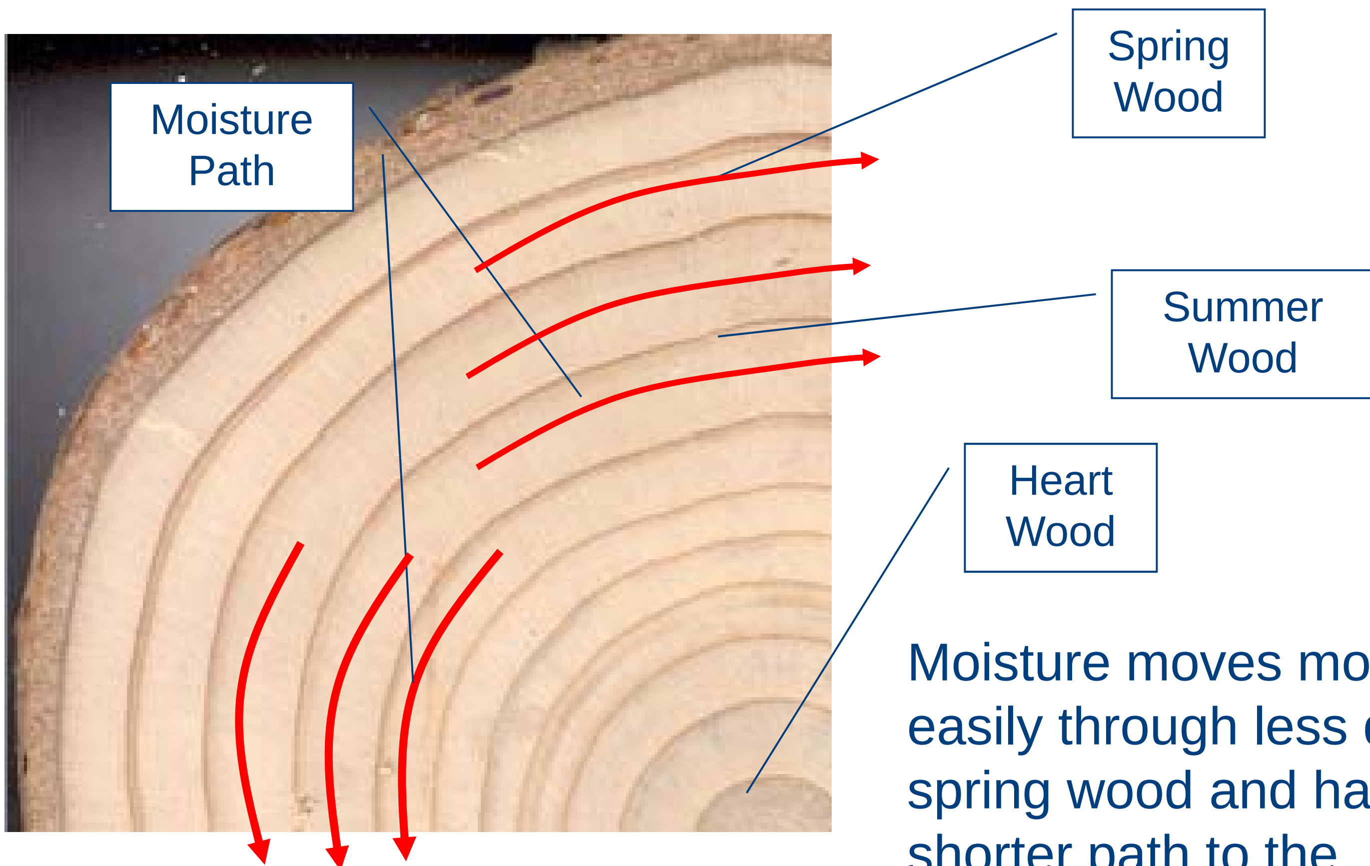
Why Split Wood for Drying?

Intertek



Summer wood is relatively dense and slows moisture migration.

Why Split Wood for Drying?



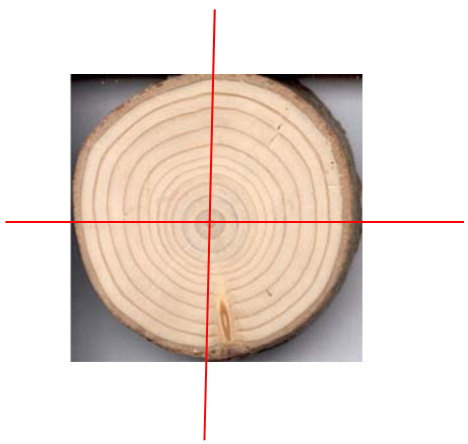
Moisture moves more easily through less dense spring wood and has a shorter path to the surface in splits.

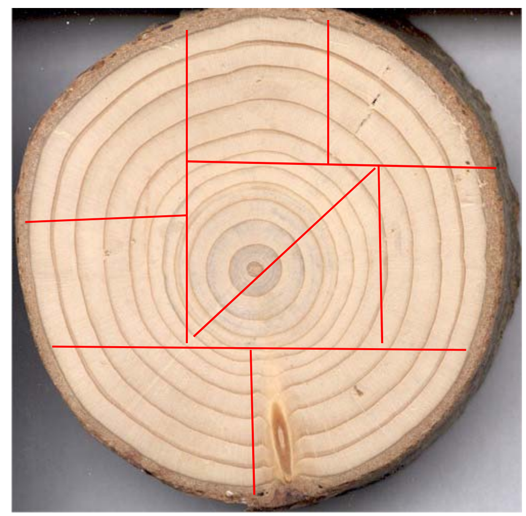
Recommendation – Split Almost Everything

Split rounds from about 3” to 8” diameter into halves.

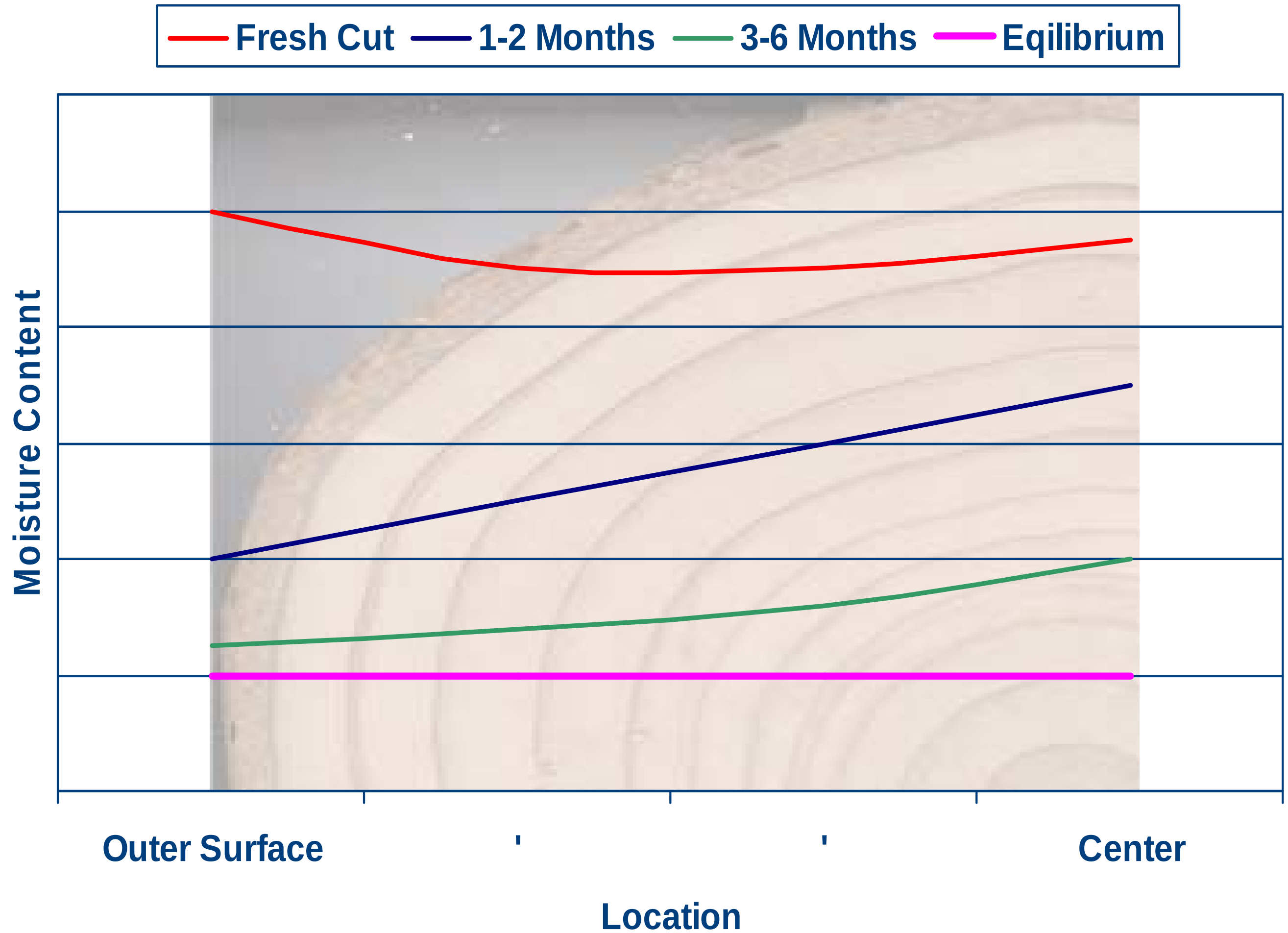
Split rounds 8” and larger into at least quarters.

Chunk large diameter logs into pieces with a maximum dimension of 8 to 12”.





Moisture Distribution



Factors That Speed Drying

Temperature –each 20 ºF increase in temperature doubles the drying rate. Stack in a sunny location if possible.

Wind – Air movement speeds drying.

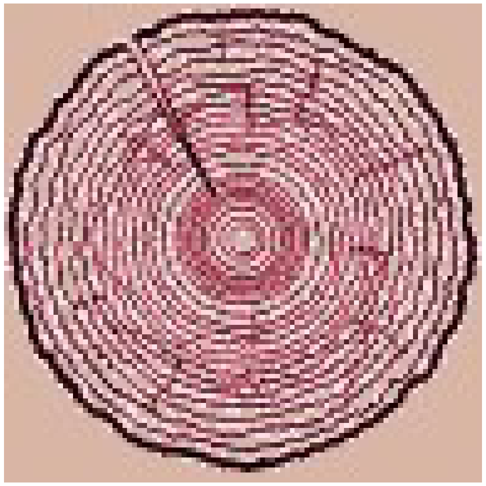
Ventilation – Stack wood loosely and perpendicular to prevailing wind.

Covering – cover the top of the pile only with plastic or tarp to keep off rain. Surface wetting will dry off quickly.

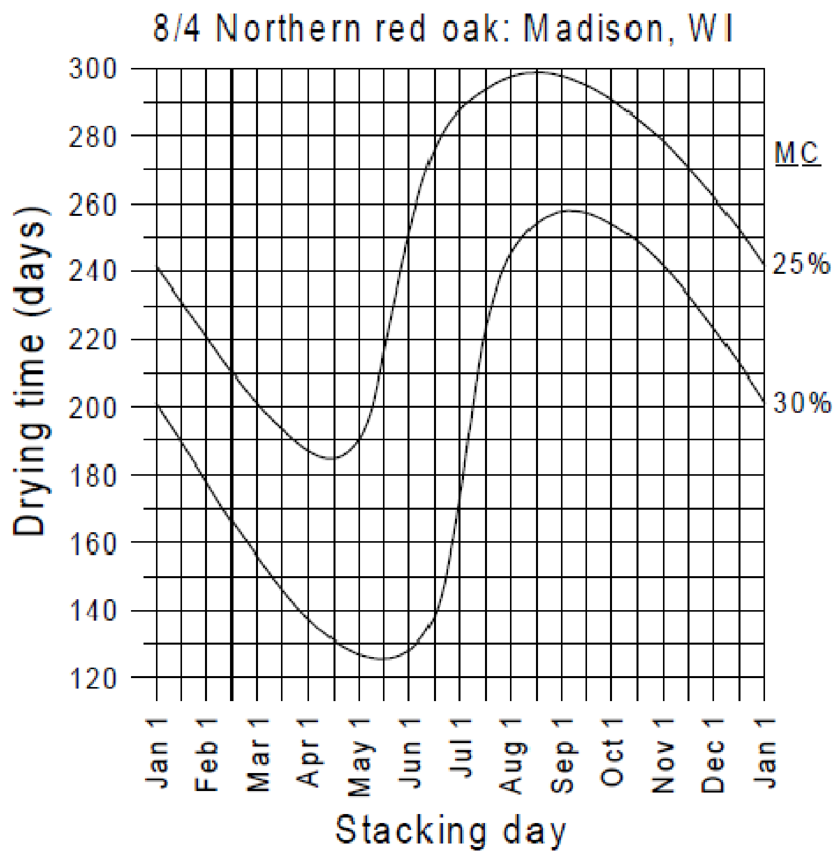
Elevate off ground.

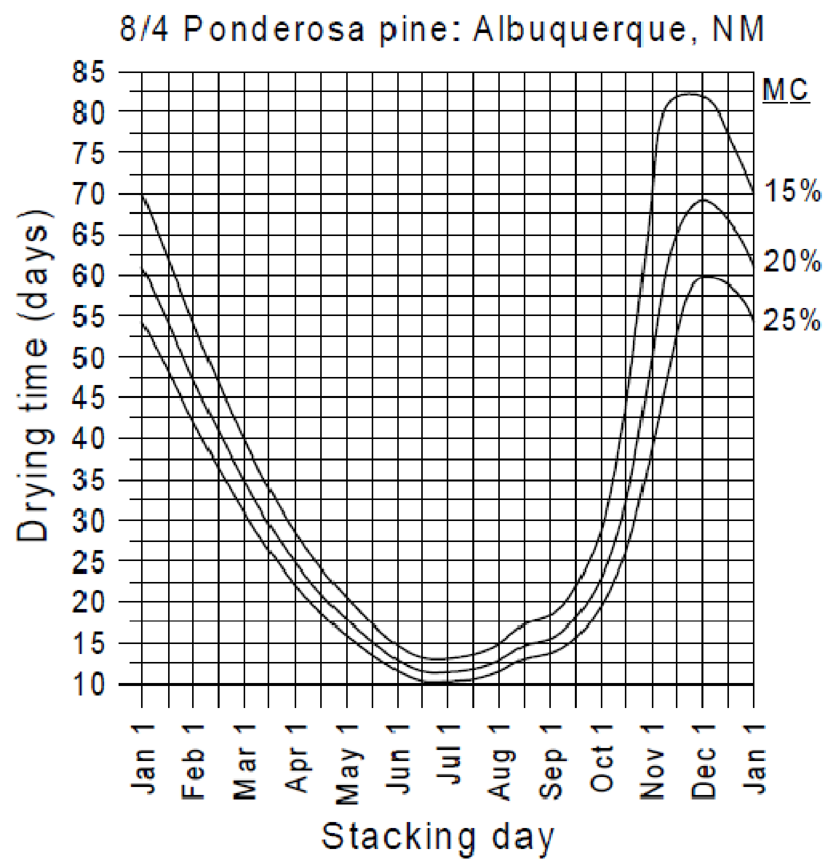
How to tell wood is seasoned.

- A moisture meter is, of course, the best way to determine MC. But there are other simple indicators that wood is reasonably well seasoned.
  - Bark loose or falling off.
  - Checking and splitting.
  - Ringing sound vs. dull thump when struck.
  - Relative Weight.
  - Easier to split.



Drying Times – Depend on Wood and Weather (US Forest Products Lab- Estimates of Air Drying Times for Several Hardwoods and Softwoods)





Drying Times – Depend on Wood and Weather

In general – Cut, split and stack your wood by April and it will be ready to use by October.

If you can cut two years ahead, and you stack and store cordwood reasonably, the MC should be in a 15 to 25% range.

Questions?