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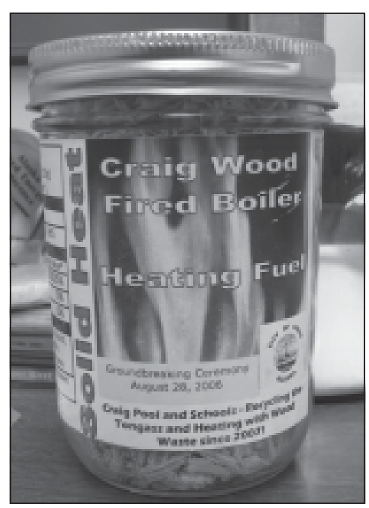
# Fuelwood Characteristics of Northwestern Conifers and Hardwoods (Updated)

Pamela L. Wilson, James W. Funck, and Robert B. Avery



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Updated, Reformatted, and Edited by:

Daniel J. Parrent, James W. Funck, James Reeb, and Allen M. Brackley

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## Abstract

**Wilson, Pamela L.; Funck, James W.; Avery, Robert B. 2010.** Fuelwood characteristics of northwestern conifers and hardwoods. Updated by Parrent, Daniel J.; Funck, James W.; Reeb, James; Brackley, Allen M., eds. Gen. Tech. Rep. PNW-GTR-810. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 50 p. (First published 1987, Res. Bull. 60, Forest Research Laboratory, College of Forestry, Oregon State University, Corvallis, OR).

This report is an update of the original publication by Oregon State University in 1987 (Resource Bulletin 60). According to agreements, researchers at the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station and the Juneau Economic Development Council worked with Oregon State University to update this reference concerning wood energy properties. The fuelwood characteristics were reformatted and presented in tabular form, and a literature review was conducted to check for additional information published since 1987. This report provides fuelwood values for 34 conifer and 20 hardwood species found in the Pacific Northwest and Alaska. Values are presented for the following characteristics: specific gravity of wood and bark, percentage moisture content of wood and bark, higher heating value of wood and bark, percentage ash of wood and bark, percentage bark by volume, and ultimate analysis of wood and bark (percentage of carbon, hydrogen, oxygen, nitrogen, and sulfur).

Keywords: Fuelwoods, heating value, British thermal unit values, Pacific Northwest.

## Preface

British thermal unit (Btu) is a standard measure of energy used in the United States to evaluate the potential of fuel. As personnel from the U.S. Department of Agriculture, Forest Service, Alaska Wood Utilization Research and Development Center (WUC) and Juneau Economic Development Council (JEDC) worked on projects to review renewable energy use, there was a constant need for this information. In the search to locate sources that provided Btu values for Pacific Northwest species, the researchers found references to Oregon State University (OSU), College of Forestry, Research Bulletin 60, published in September 1987.

It rapidly became a standard reference used by Daniel Parrent of JEDC and Allen Brackley of WUC for research projects concerned with wood energy use and systems. Both users recognized that although the existing publication was comprehensive and the best source that either had located, it was difficult to use. Parrent took it upon himself to reformat the information into tables that allowed easier access to the data. Almost simultaneously, Brackley contacted Jim Funck at OSU and suggested that the publication contained very timely and valuable information and, therefore, should be reprinted and made more generally available to anyone working with wood energy systems. Funck and James Reeb at OSU conducted a literature review to check for any additional information published since 1987, and worked with Parrent and Brackley to publish the updated tables.

The original version of the OSU report contained fuelwood values for species in the Pacific Northwest. This report adds black spruce (*Picea mariana* [Mill.] Britton, Sterns & Poggenb.), a species in the boreal forest of northern Alaska. Some of the information for black spruce resulted from research at the University of Alaska Fairbanks, Agriculture and Forestry Experiment Station.

It was agreed that the reprint would publish the text in the original form, taking into consideration any new reference material and presenting fuelwood characteristics in tabular form. The original authors (Pamela L. Wilson, James W. Funck, and Robert B. Avery) would be credited as authors of the updated version. The work of the above-mentioned individuals would be recognized by adding their names to the formal title page and citation for the updated version of *Fuelwood Characteristics of Northwestern Conifers and Hardwoods* (originally published by the Forest Research Laboratory, Oregon State University as Research Bulletin 60 in September 1987).

In response to peer reviews, moisture and ash contents on wet basis were added along with tables in the International System of units (metric).

Updated, reformatted, and edited by:

Daniel J. Parrent
James W. Funck
James Reeb
Allen M. Brackley

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## Introduction

This report is intended to provide a convenient summary of fuelwood values for tree species of the Pacific Northwest. It collates the published values and gives accurate ranges by species for each fuelwood characteristic.

Species selected are those that were inventoried by the Pacific Northwest Forest and Range Experiment Station for Washington, Oregon, Idaho, and northern California. We included only species that appear in the inventory for which fuelwood information was found in the literature. Thirty-three conifer and 20 hardwood species appeared in the original report. An additional conifer, black spruce (*Picea mariana* [Mill.] B.S.P.), was added to this updated version. In the original work, scientific names were verified using Little (1979) if the scientific name in the original reference differed from current usage at that time. If the scientific name could not be verified as either a current or a former name, the reference was not included. This update included checking the species list with the names found in the U.S. Department of Agriculture's PLANTS Database (USDA NRCS 2009). Current synonyms were added to the list for some species, and common names were also updated.

The following fuelwood characteristics are included in this report:

- Specific gravity of wood and bark
- Percentage moisture content of wood and bark
- Higher heating value of wood and bark
- Percentage ash of wood and bark
- Percentage bark by volume
- Ultimate analysis of wood and bark:
    - Percentage carbon
    - Percentage hydrogen
    - Percentage oxygen
    - Percentage nitrogen
    - Percentage sulfur

The range of values found for each category is given, as well as any finer breakdown supplied in the published reports. For example, for some species, the moisture content is given for heartwood and sapwood or for inner and outer bark. Not all categories appear for all species, as pertinent values often were not available.

We used original sources whenever possible. Literature reviews are cited only when values given differ from any other published values and the original source is not easily available. We made no attempt to go back to the original references from Isenberg (1980, 1981). The values we list are as published; they were not necessarily determined according to accepted procedures, and the original authors did not convert units.[1]

Hale (1933) listed the gross calorific value of wood in British thermal units (Btu) per air-dry (AD) cord. The wood was burned in a coal-fired, domestic hot-water heater. In calculating the heating values, we assumed that one cord of split wood cut into 1-ft lengths contained 90 $ft^3$ of solid material and that the moisture content of the split wood was 20 percent on a total-weight (TW) basis (green weight basis). Weights per cubic foot of different species of wood were taken from the records of the Forest Products Laboratories of Canada (Smith 1970).

Other references give heating values in Btu per AD pound, Btu per oven-dry (OD) pound, or kilocalorie (kcal) per kilogram. If heating values originally were given in both Btus and other units, we list only the Btu heating value.

The values provided by Sargent (1885) were listed in this publication for percentage of ash from wood, but his specific gravity values were listed only when no other information was available. Sargent's values for specific gravity were determined on an OD-volume basis, whereas this paper generally reports specific gravity on a green-volume basis.

Specific gravity of wood and bark can be determined on the basis of green, AD, or OD volume. The calculation for specific gravity is shown in equation 1.

$$\text{Specific gravity} = \frac{\text{Weight (green, AD, or OD)}}{\text{Weight of displaced water at 4 °C}} \qquad (1)$$

In green wood or bark, the cell walls are saturated, giving the largest possible volume, the largest water displacement, and therefore, the lowest specific gravity. Determination of specific gravity with OD volume results in the least displacement of water and gives the highest specific gravity. The density of OD wood in pounds per cubic feet can be estimated by multiplying the specific gravity by the weight of 1 $ft^3$ of water at 4 °C (62.4 $lb/ft^3$). The higher the density (or specific gravity), the more Btus per cubic foot of wood are available for combustion.

The moisture content of wood and bark is very important to combustion. Moisture reduces both heating value and furnace efficiency. Maintaining combustion at moisture contents over 60 percent (TW basis) is very difficult, if not

[1] Metric conversion factors are provided at the end of the report. In this update, English measurements have been converted to metric units, and these are shown in the tables.

impossible (Karchesy and Koch 1979). Combustion can be divided into three processes: (1) moisture is evaporated, requiring approximately 1,100 Btu per pound of water, (2) the fuel temperature rises until the volatiles are driven off and burned, (3) the remaining carbon is burned (Karchesy and Koch 1979). Thus, much available heat is used to evaporate the moisture in the fuel. The minimum amount of air needed for combustion (the theoretical air) does not depend on the moisture content and can be calculated from the ultimate analysis (percentage of carbon, hydrogen, oxygen, nitrogen, and sulfur); Karchesy and Koch (1979) provided a good description of this calculation.

In the forest industry, moisture content is generally given on the OD basis, whereas combustion engineers generally use the wet basis. In the original report, moisture contents were given on an OD basis. Methods for calculating the moisture content and for converting between the two bases are shown in equations (2) through (5) (table 1). This update provides these converted moisture contents on a wet basis in the tables. Additional details on these conversions can be found in the appendix.

The higher heating value (HHV) of wood and bark (the maximum energy that can be produced) is determined with an oxygen bomb calorimeter and is calculated at zero percent moisture content. Any moisture in the wood or bark reduces that maximum value proportionately. If the moisture content on a wet basis is known, the heating value at that moisture content can be calculated according to equation (6) (see table 1). For example, for a moisture content of 50 percent on a TW basis (100 percent based on OD weight) and a HHV of 8,500 Btu/lb,

$$\text{Heating value} = \frac{100 - 50}{100}(8{,}500) = 4{,}250 \text{ Btu/lb}$$

Neither HHV (Btu per OD pound) nor percentage ash content differs widely between species. In nearly all species, the HHV can be considered to be 9,000 Btu/OD lb ± 10 percent.[2] The ash content generally ranges from 0.1 to 1 percent for wood and from 1 to 3 percent for bark (see footnote 2). If ash content in excess of these values is obtained, it can reasonably be assumed that the material has been contaminated during handling and processing. The reported values for the species in this publication could have come from samples with extraneous material, and final values cannot be adjusted for this condition.

[2] Zerbe, J.I. 1987. Personal communication. Energy specialist, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726.

**Table 1—Equations for calculating percentage moisture content (equations [2] through [5]) and heating value (equation [6]) of wood and bark**

| Equation | | | | Equation number |
|---|---|---|---|---|
| Percentage moisture content (OD basis) | = | $\frac{\text{wet weight} - \text{OD weight}}{\text{OD weight}}$ | x 100 | (2) |
| Percentage moisture content (TW basis) | = | $\frac{\text{wet weight} - \text{OD weight}}{\text{wet weight}}$ | x 100 | (3) |
| Percentage moisture content (OD basis) | = | $\frac{\text{percentage moisture content (TW basis)}}{100 - \text{percentage moisture content (TW basis)}}$ | x 100 | (4) |
| Percentage moisture content (TW basis) | = | $\frac{\text{percentage moisture content (OD basis)}}{100 + \text{percentage moisture content (OD basis)}}$ | x 100 | (5) |
| Gross heating value | = | $\frac{100 - \text{percentage moisture content (TW basis)}}{100}$ | x HHV | (6) |

Note: OD = oven-dry; TW = total weight or green basis; HHV = higher heating value.

Neither ultimate nor proximate (moisture, volatile, carbon, and ash content and HHV) analyses differ much between species in Btu per OD weight. Arola (1976) gave typical ultimate and proximate analysis results by softwood (conifer) and hardwood for wood and bark (table 2).[3] Some totals are not 100 percent, because different sources of data for ash content were averaged. The ultimate analyses in this publication also may not add up to 100 percent, because the ultimate analysis includes ash, and the range of ash content is listed separately.

[3] A comparison of table 2 to the general ash content ranges mentioned previously shows higher values in table 2. The source for the general values, Zerbe, has concerns with Arola's methods and does not think the values in table 2 are realistic. Zerbe believes that the proximate analysis had to be based on something other than the OD condition (which standard methods require). If the original weight of the material is not taken at the OD condition, then the excess moisture is driven off as volatile matter; although there is the same absolute amount of fixed carbon, it is a reduced percentage of the original weight. Arola also mentioned a connection between ultimate analysis and quantifying potential pollutants. Zerbe, however, believes that comparing fixed carbon and ultimate carbon by the two methods of analysis and inferring that the difference is the contribution of pollution is not necessarily valid.

**Table 2—Typical proximate and ultimate analyses of wood and bark**

| | Proximate | | | Ultimate | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Volatile matter | Fixed carbon | Ash[a] | C | H | O | N | S | Ash[a] |
| | | | | *Percent* | | | | | |
| Hardwood | | | | | | | | | |
| Wood | 77.3 | 19.4 | 3.4 | 50.8 | 6.4 | 41.8 | 0.4 | — | 0.9 |
| Bark | 76.7 | 18.6 | 4.6 | 51.2 | 6.0 | 37.9 | 0.4 | — | 5.2 |
| Softwood | | | | | | | | | |
| Wood | 77.2 | 22.0 | 1.6 | 52.9 | 6.3 | 39.7 | 0.1 | — | 1.0 |
| Bark | 73.3 | 23.7 | 3.0 | 53.1 | 5.9 | 37.9 | 0.2 | — | 2.3 |

Note: C = carbon, H = hydrogen, O = oxygen, N = nitrogen, S = sulfur.

It appears that in the reported proximate analysis, the weight of the tested material was not taken at the oven-dry condition. The calculation of percentage of fixed carbon in this situation results in a value that is lower than would be obtained from application of standard methods (original weight taken at the oven-dry condition).

[a] Ash percentages may differ because different data sources were averaged.

Source: Arola 1976.

## Conifers

The data for northwestern conifers listed below are presented in six tables. The physical properties are given in table 3 for the bark and table 4 for the wood. Table 5 provides the heating values, ash content, and analysis of the bark of the conifers as per the original publication. Table 6 provides these same properties but converted into metric units and ash content on wet basis. Table 7 provides the heating values and ash content of the wood of the conifer species. Like table 6, table 8 shows the data converted into metric units and ash content on wet basis.

## Conifer species

| Scientific name | Common name |
|---|---|
| *Abies amabilis* (Douglas ex Louden) Douglas ex Forbes | Pacific silver fir |
| *Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr. | White fir |
| *Abies grandis* (Douglas ex D. Don) Lindl. | Grand fir |
| *Abies lasiocarpa* (Hook.) Nutt. | Subalpine fir |
| *Abies magnifica* A. Murray | California red fir, Shasta red fir |
| *Abies procera* Rehder | Noble fir |

| **Scientific name** | **Common name** |
|---|---|
| *Calocedrus decurrens* (Torr.) Florin | Incense cedar |
| *Chamaecyparis lawsoniana* (A. Murray) Parl. | Port Orford cedar |
| *Cupressus nootkatensis* (D. Don) Spach | Alaska yellow-cedar, Alaska cedar |
| *Chamaecyparis nootkatensis* D. Don | Alaska yellow-cedar, Alaska cedar |
| *Juniperus occidentalis* Hook. | Western juniper |
| *Larix occidentalis* Nutt. | Western larch |
| *Libocedrus decurrens* Torr. | Incense cedar |
| *Picea engelmannii* Parry ex Engelm. | Engelmann spruce |
| *Picea glauca* (Moench) Voss | White spruce |
| *Picea mariana* (Mill.) Britton, Sterns & Poggenb. | Black spruce |
| *Picea pungens* Engelm. | Blue spruce |
| *Picea sitchensis* (Bong.) Carr. | Sitka spruce |
| *Pinus albicaulis* Engelm. | Whitebark pine |
| *Pinus aristata* Engelm. | Bristlecone pine |
| *Pinus attenuata* Lemmon | Knobcone pine |
| *Pinus contorta* Douglas ex Loud. | Lodgepole pine |
| *Pinus jeffreyi* Balf. | Jeffrey pine |
| *Pinus lambertiana* Douglas | Sugar pine |
| *Pinus monticola* Douglas ex D. Don | Western white pine |
| *Pinus muricata* D. Don | Bishop pine |
| *Pinus ponderosa* C. Lawson | Ponderosa pine |
| *Pinus radiata* D. Don | Monterey pine, radiata pine |
| *Pinus sabiniana* Douglas ex Douglas | California foothill pine, digger pine, gray pine |
| *Pseudotsuga menziesii* (Mirb.) Franco | Douglas-fir |
| *Sequoia sempervirens* (Lamb. ex D. Don) Endl. | Redwood |
| *Sequoiadendron giganteum* (Lindl.) J. Buchholz | Giant sequoia |
| *Taxus brevifolia* Nutt. | Pacific yew |
| *Thuja plicata* Donn. ex D. Don | Western redcedar |
| *Tsuga heterophylla* (Raf.) Sarg. | Western hemlock |
| *Tsuga mertensiana* (Bong.) Carr. | Mountain hemlock |

**Table 3—Physical properties of northwestern conifers (bark)**

| Scientific name | Common name | Specific gravity | | Moisture content | | | Bark by volume | |
|---|---|---|---|---|---|---|---|---|
| | | Value[a] | Citation number | Oven-dry basis | Total-weight basis | Citation number | Value | Citation number |
| | | | | – – – – *Percent* – – – – | | | *Percent* | |
| *Abies amabilis* | Pacific silver fir | | | | | | 12 | 85 |
| | Inner bark | 0.53 | 73 | 77.4 | 43.6 | 73 | | |
| | Outer bark | .58 | 73 | 39.6 | 28.4 | 73 | | |
| | Mixed | .44 | 74 | | | | | |
| | Mixed | .68[b] | 27 | | | | | |
| *Abies concolor* | White fir | | | | | | 9.7-28.6 | 28,85 |
| | Inner bark | .69[c] | 7 | | | | | |
| | Outer bark | .60[c] | 7 | | | | | |
| | Mixed | .62[b] | 27 | | | | | |
| *Abies grandis* | Grand fir | | | | | | | |
| | Inner bark | .63 | 73 | 81 | 44.8 | 73 | | |
| | Outer bark | .70 | 73 | 51.4 | 34.0 | 73 | | |
| | Mixed | .57-.64[b] | 27 | 50.8 | 33.4 | 53 | | |
| *Abies lasiocarpa* | Subalpine fir | .50-.55[b] | 27 | | | | | |
| *Abies magnifica* | California red fir | | | 22.2 | 18.2 | 53 | | |
| | Inner bark | .69[c] | 7 | | | | | |
| | Outer bark | .50[c] | 7 | | | | | |
| | Mixed | .50[b] | 27 | | | | | |
| *Abies procera* | Noble fir | .56[b] | 27 | | | | | |
| *Chamaecyparis lawsoniana* | Port Orford cedar | .33-.52[b] | 27 | | | | | |
| *Chamaecyparis nootkatensis* | Alaska yellow-cedar | | | | | | 11-13.1 | 16,74 |
| | Inner bark | .41 | 73 | 145 | 59.2 | 73 | | |
| | Outer bark | .38 | 73 | 79.4 | 44.3 | 73 | | |
| | Mixed | .63[b] | 27 | | | | | |
| *Juniperus occidentalis* | Western juniper | .48[b] | 27 | | | | | |
| *Larix occidentalis* | Western larch | | | | | | 21 ± 6.5 | 76 |
| | Inner bark | .37-.43 | 29,73 | 98.6 | 49.6 | 73 | | |
| | Outer bark | .33-.35 | 29,73 | 44.0 | 30.6 | 73 | | |
| | Mixed | .32-.33 | 25,29,74 | | | | | |

**Table 3—Physical properties of northwestern conifers (bark) (continued)**

| | | Specific gravity | | Moisture content | | | Bark by volume | |
|---|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value[a] | Citation number | Oven-dry basis | Total-weight basis | Citation number | Value | Citation number |
| | | | | – – – – *Percent* – – – – | | | *Percent* | |
| *Libocedrus decurrens* | Incense cedar | | | 25 | 20 | 53 | 29 ± 9.6 | 76 |
| | Outer bark | .30[c] | 7 | | | | | |
| | Mixed | .27[b] | 27 | | | | | |
| *Picea engelmannii* | Engelmann spruce | | | | | | | |
| | Inner bark | .41-.45 | 29,73 | 121 | 55 | 73 | | |
| | Outer bark | .52-.53 | 29,73 | 60.5 | 37.7 | 73 | | |
| | Mixed | .43-.51 | 25,29,73,74 | | | | | |
| | Mixed | .80[b] | 27 | | | | | |
| *Picea glauca* | White spruce | | | | | | | |
| | Inner bark | .45 | 73 | 104 | 51 | 73 | 8.6-11.7 | 85 |
| | Outer bark | .43-.50 | 29,73 | 50 | 33 | 73 | | |
| | Mixed | .39 | 25,29 | | | | | |
| | Mixed | .62-.68[b] | 27 | | | | | |
| *Picea mariana* | Black spruce | | | 45.6 | 31.3 | 77 | | |
| *Picea pungens* | Blue spruce | | | | | | | |
| *Picea sitchensis* | Sitka spruce | | | | | | | |
| | Inner bark | .44 | 73 | 112 | 53 | 73 | | |
| | Outer bark | .62 | 73 | 55.3 | 35.6 | 73 | | |
| | Mixed | .63[b] | 27 | | | | | |
| *Pinus albicaulis* | Whitebark pine | | | | | | | |
| *Pinus aristata* | Bristlecone pine | | | | | | | |
| *Pinus attenuata* | Knobcone pine | | | | | | 11.1 | 43 |
| *Pinus contorta* | Lodgepole pine | | | | | | 10 ± 2.4 | 16,74,76 |
| | Inner bark | .32-.34 | 29,73 | 128 | 56 | 73 | | |
| | Outer bark | .45-.51 | 29,73 | 42 | 29 | 73 | | |
| | At 1.0 foot | .42 | 74 | | | | | |
| | At 4.5 feet | .40 | 74 | | | | | |
| | Mixed | .38 | 25,29 | | | | | |
| | Mixed | .60[b] | 27 | | | | | |
| *Pinus jeffreyi* | Jeffrey pine | | | | | | | |
| | Outer bark | .36[c] | 7 | | | | | |
| *Pinus lambertiana* | Sugar pine | | | | | | | |
| | Outer bark | .34[c] | 7 | | | | | |
| | Mixed | .38[b] | 27 | | | | | |

**Table 3—Physical properties of northwestern conifers (bark) (continued)**

| Scientific name | Common name | Specific gravity | | Moisture content | | | Bark by volume | |
|---|---|---|---|---|---|---|---|---|
| | | Value[a] | Citation number | Oven-dry basis | Total-weight basis | Citation number | Value | Citation number |
| | | | | – – – – Percent – – – – | | | Percent | |
| *Pinus monticola* | Western white pine | | | | | | 17 ± 8.3 | 16,21,76 |
| | Inner bark | .31 | 73 | 118 | 54 | 73 | | |
| | Outer bark | .54 | 73 | 75 | 43 | 73 | | |
| | Mixed | .51 | 21 | 64-82 | 39-45 | 21,60 | | |
| | Mixed | .63[b] | 27 | | | | | |
| *Pinus muricata* | Bishop pine | | | | | | | |
| *Pinus ponderosa* | Ponderosa pine | | | | | | 5.9-27.2 | 16,50,76,82 |
| | Inner bark | .34-.36 | 29,73 | 77.8 | 43.8 | 73 | | |
| | Outer bark | .34-.35 | 29,73 | 21 | 17 | 73 | | |
| | Outer bark | .27[c] | 7 | | | | | |
| | Mixed | .28-.35 | 25,29,74 | 15.3-40.4 | 13.3-28.8 | 53,60 | | |
| *Pinus radiata* | Monterey pine | | | | | | | |
| *Pinus sabiniana* | California foothill pine | | | | | | 18.3 | 43 |
| *Pseudotsuga menziesii* | Douglas-fir | | | | | | 9.4-35 | 16,21,74,76, 83,85 |
| | Inner bark | .42-.46 | 29,73,74 | 133 | 57.1 | 73 | | |
| | Outer bark | .40-.46 | 29,73,74 | 80.3 | 44.5 | 73 | | |
| | Outer bark | .48[c] | 7 | | | | | |
| | Mixed | .41-.51 | 21,25,74 | | | | | |
| | Mixed | .41-.54[b] | 27 | | | | | |
| | Old growth | | | 8.9 | 8.2 | 53 | | |
| | Second growth | | | 97.2 | 49.3 | 53 | | |
| | At test | | | 48-80.2 | 32-44.5 | 14,21 | | |
| *Sequoia sempervirens* | Redwood | | | 13.9 | 12.2 | 53 | | |
| | Inner bark | .48[c] | 7 | | | | | |
| | Outer bark | .43[c] | 7 | | | | | |
| | Mixed | .46[b] | 27 | | | | | |
| | Old growth | | | | | | 14-16 | 58 |
| | Second growth | | | | | | 12.6-13 | 58 |
| *Sequoiadendron giganteum* | Giant sequoia | | | | | | | |
| *Taxus brevifolia* | Pacific yew | .35 | 21 | 97.2 | 49.3 | 21 | 3.4 | 21 |
| | Pacific yew | .62[b] | 27 | | | | | |

**Table 3—Physical properties of northwestern conifers (bark) (continued)**

| Scientific name | Common name | Specific gravity | | Moisture content | | | Bark by volume | |
|---|---|---|---|---|---|---|---|---|
| | | Value[a] | Citation number | Oven-dry basis | Total-weight basis | Citation number | Value | Citation number |
| | | | | – – – – *Percent* – – – – | | | *Percent* | |
| *Thuja plicata* | Western redcedar | | | | | | | |
| | Inner bark | .36 | 73 | 88.5 | 46.9 | 73 | | |
| | Outer bark | .38 | 73 | 37.4 | 27.2 | 73 | | |
| | Mixed | .35-.37 | 21,74 | 44.7-47.4 | 30.9-32.2 | 21,53 | 9 ± 4.1 | 21,76 |
| | Mixed | .44[b] | 27 | | | | | |
| | Coastal | | | | | | 13.9 | 16 |
| | Interior | | | | | | 15.2 | 16 |
| *Tsuga heterophylla* | Western hemlock | | | | | | | |
| | Inner bark | .38-.46 | 29,51,73,74 | 86-134 | 46-57 | 51,73 | | |
| | Outer bark | .45-.56 | 29,51,73,74 | 38-65.2 | 28-39.5 | 51,73 | | |
| | Mixed | .44-.46 | 21,25,29,74 | 65-74 | 39-43 | 14,21 | 6.3-16.3 | 21,76,85 |
| | Mixed | .59[b] | 27 | | | | | |
| | Coastal | | | | | | 16.3 | 16 |
| | Interior | | | | | | 17.9 | 16 |
| *Tsuga mertensiana* | Mountain hemlock | .46[b] | 27 | | | | | |

[a] Green volume, oven-dry weight unless otherwise noted.
[b] Oven-dry volume, oven-dry weight.
[c] Volume at 13 percent ± 2 percent moisture content, oven-dry weight.

## Table 4—Physical properties of northwestern conifers (wood)

| Scientific name | Common name | Specific gravity: Value[a] | Specific gravity: Citation number | Moisture content, Sapwood: OD basis | Sapwood: TW basis | Sapwood: Citation | Heartwood: OD basis | Heartwood: TW basis | Heartwood: Citation | Mixed: OD basis | Mixed: TW basis | Mixed: Citation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | — — — *Percent* — — — | | | — — — *Percent* — — — | | | — — — — *Percent* — — — — | | |
| *Abies amabilis* | Pacific silver fir | 0.28-0.55 | 20,47,48, 75,85 | 164 | 62.1 | 16,57 | 55 | 35 | 57,16 | 66-74 | 40-43 | 16,20 49,75 |
| *Abies concolor* | White fir | .26-.54 | 22,47,49, 85,86,90 | 98 | 49 | 57 | 160 | 62 | 57 | 110-154 | 52-61 | 29,49,90 |
| *Abies grandis* | Grand fir | .24-.55 | 47,49 | 136 | 58 | 57 | 91 | 48 | 57 | 94 | 48 | 49 |
| *Abies lasiocarpa* | Subalpine fir | .30-.38 | 4,49,75,83 | 153 | 60 | 16 | 56 | 36 | 16 | 47-67 | 32-40 | 16,49,57,75 |
| *Abies magnifica* | California red fir | .31-.46 | 47,49,68 | | | | | | | 108 | 52 | 49,57 |
| *Abies procera* | Noble fir | .26-.44 | 47,49,56 | 115 | 53 | 57 | 34 | 25 | 57 | 36-70 | 26-41 | 49,56 |
| *Chamaecyparis lawsoniana* | Port Orford cedar | .39-.40 | 49,78,87 | 98-200 | 49-67 | 57,78 | 40-50 | 29-33 | 57,78 | 43 | 30 | 49 |
| *Chamaecyparis nootkatensis* | Alaska yellow-cedar | .42 | 20,49 | 166 | 62 | 57 | 32 | 24 | 57 | 34-52 | 25-34 | 16,20,49 |
| *Juniperus occidentalis* | Western juniper | .58[b] | 64 | 128-216 | 56-68 | 39 | 46-87 | 32-47 | 39 | 64-178 | 39-64 | 39 |
| *Larix occidentalis* | Western larch | .37-.55 | 20,21,47, 49,75,83 | 110-119 | 52-54 | 16,57, 87 | 35-54 | 26-35 | 16,56,57 | 49.4-63.9 | 33.1-39.0 | 20,21, 49,75 |
| *Libocedrus decurrens* | Incense cedar | .35 | 49 | 213 | 68 | 57 | 40 | 29 | 57 | 108 | 52 | 49 |
| *Picea englemannii* | Englemann spruce | .23-.58 | 5,20,47,49, 75,83 | 173 | 63 | 57 | 51 | 34 | 57 | 58-100 | 37-50 | 20,49,75 |
| *Picea glauca* | White spruce | .35-.46 | 20,49,75,83,85 | 163 | 62 | 16 | 51 | 34 | 16 | 50-75 | 33-43 | 16,20,49,75 |
| *Picea mariana* | Black spruce | .5-.55 | 77 | | | | | | | | | |
| *Picea pungens* | Blue spruce | .37[b] | 64 | | | | | | | | | |
| *Picea sitchensis* | Sitka spruce | .35-.37 | 20,49,83 | 142 | 59 | 57 | 41 | 29 | 57 | 42-43 | 29-30 | 16,20,49 |
| *Pinus albicaulis* | Whitebark pine | .42[b] | 33,34,64 | | | | | | | | | |
| *Pinus aristata* | Bristlecone pine | .56[b] | 64 | | | | | | | | | |
| *Pinus attenuata* | Knobcone pine | .35-.42 | 43,72 | | | | | | | | | |
| *Pinus contorta* | Lodgepole pine | | | | | | | | | | | |
| | Sapwood | | | | | | | | | | | |
| | Green | .36 | 44 | 163 | 62 | 44 | | | | | | |
| | Dead down | .36 | 44 | 15 | 13 | 44 | | | | | | |
| | Dead standing | .37 | 44 | 18 | 15 | 44 | | | | | | |
| | At test | | | 115-120 | 53-55 | 16,57 | | | | | | |
| | Heartwood | | | | | | | | | | | |
| | Green | .38 | 44 | | | | 35 | 26 | 44 | | | |
| | Dead down | .36 | 44 | | | | 20 | 17 | 44 | | | |
| | Dead standing | .38 | 44 | | | | 12 | 11 | 44 | | | |
| | At test | | | | | | 38-41 | 28-29 | 16,57 | | | |
| | Mixed (at test) | .26-.55 | 20,44,47, 49,75,82 | | | | | | | 49-65 | 33-39 | 16,20,49,75 |

**Table 4—Physical properties of northwestern conifers (wood) (continued)**

| | | Specific gravity | | Moisture content | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sapwood | | | Heartwood | | | Mixed | | |
| Scientific name | Common name | Value[a] | Citation number | OD basis | TW basis | Cita-tion | OD basis | TW basis | Cita-tion | OD basis | TW basis | Cita-tion |
| | | | | – – – *Percent* – – – | | | – – – *Percent* – – – | | | – – – *Percent* – – – | | |
| *Pinus jeffreyi* | Jeffrey pine | .37 | 49 | | | | | | | 101 | 50 | 49 |
| *Pinus lambertiana* | Sugar pine | .28-.45 | 47,49 | 219 | 69 | 57 | 98 | 49 | 57 | 137 | 58 | 49 |
| *Pinus monticola* | Western white pine | | | | | | | | | | | |
| | Sapwood | | | | | | | | | | | |
| | Green | .46 | 44 | 27 | 21 | 44 | | | | | | |
| | Dead down | .35 | 44 | 34 | 25 | 44 | | | | | | |
| | Dead standing | .34 | 44 | 14 | 12 | 44 | | | | | | |
| | At test | | | 148 | 60 | 57 | | | | | | |
| | Heartwood | | | | | | | | | | | |
| | Green | .43 | 44 | | | | 28 | 22 | 44 | | | |
| | Dead down | .38 | 44 | | | | 35 | 26 | 44 | | | |
| | Dead standing | .39 | 44 | | | | 17 | 15 | 44 | | | |
| | At test | | | | | | 62 | 38 | 57 | | | |
| | Mixed (at test) | .29-.45 | 20,21,44, 47,49 | | | | | | | 54-127 | 35-56 | 16,20,21, 49,60 |
| *Pinus muricata* | Bishop pine | .45 | 71 | | | | | | | | | |
| *Pinus ponderosa* | Ponderosa pine | .27-.54 | 20,29,47,49, 50,75,82 | 148 | 60 | 16,57 | 40 | 29 | 16,57 | 71-149.2 | 42-59.9 | 6,20,49, 53,60,75 |
| *Pinus radiata* | Monterey pine | .40-.53 | 11 | 90-145 | 47-59 | 11 | 35 | 26 | 11 | | | |
| *Pinus sabiniana* | California foothill pine | .37-.43 | 43,70 | | | | | | | 102 | 51 | 70 |
| *Pseudotsuga menziesii* | Douglas-fir | .33-.59 | 20,21,47,49, 75,83,85 | 115-154 | 53-61 | 16,57 | 31-39 | 24-28 | 16,57 | 36-65.6 | 26-39.6 | 16,20, 21,49, |
| *Sequoia sempervirens* | Redwood | | | | | | | | | | | |
| | Open grown | .28 | 49 | | | | | | | 146 | 59 | 49 |
| | Close grown | .32 | 49 | | | | | | | 112 | 53 | 49 |
| | Old growth | .36-.38 | 29,83 | 210 | 68 | 57 | 86 | 46 | 57 | | | |
| | Second growth | .33-.34 | 29,83 | | | | | | | 127 | 56 | 57 |
| | Mixed | .24-.36 | 3 | | | | | | | 75-155 | 43-61 | 3,29,53 |
| *Sequoiadendron giganteum* | Giant sequoia | | | | | | | | | | | |
| | Young growth | .35 | 59 | | | | | | | | | |
| | Old growth | .30 | 59 | | | | | | | | | |
| | Mixed | .34 | 12 | | | | | | | 180 | 64 | 12 |
| *Taxus brevifolia* | Pacific yew | .59-.60 | 21,49 | | | | | | | 44-50.2 | 31-33.4 | 21,49 |
| *Thuja plicata* | Western redcedar | .27-.42 | 20,21,47,49,75 | 249 | 71 | 57 | 58 | 37 | 57 | 34.1-62 | 25.4-38 | 16,20,21, 49,75 |
| *Tsuga heterophylla* | Western hemlock | .30-.52 | 20,21,23,47, 49,75,83,85 | 143-170 | 59-63 | 16,57 | 55-85 | 35-46 | 16,57 | 64.6-92 | 39.3-48 | 6,20,21, 23,49,75 |
| *Tsuga mertensiana* | Mountain hemlock | .37-.45 | 49,93 | | | | | | | 62-68 | 38-40 | 49,93 |

Note: OD = oven dry, TW = total weight.

[a] Green volume, oven-dry weight unless otherwise noted.

[b] Oven-dry volume, oven-dry weight.

**Table 5—Higher heating values and ash content of northwestern conifers (bark)**

| Scientific name | Common name | Heating value: Value | Heating value: Citation number | Analysis: Ash[a] | Analysis: Citation number | Analysis: Carbon Hydrogen Oxygen Nitrogen Sulfur | Analysis: Citation number |
|---|---|---|---|---|---|---|---|
| | | *Btu/OD lb* | | *Percent* | | *Percent* | |
| *Abies amabilis* | Pacific silver fir | | | | | | |
| *Abies concolor* | White fir | | | | | | |
| *Abies grandis* | Grand fir | 9,641 | 36 | 2.5 | 53 | | |
| *Abies lasiocarpa* | Subalpine fir | | | | | | |
| *Abies magnifica* | California red fir | | | 2.6 | 53 | | |
| *Abies procera* | Noble fir | | | | | | |
| *Chamaecyparis lawsoniana* | Port Orford cedar | | | | | | |
| *Chamaecyparis nootkatensis* | Alaska yellow-cedar | | | | | | |
| *Juniperus occidentalis* | Western juniper | | | | | | |
| *Larix occidentalis* | Western larch | 8,280-9,162<br>8,204[b]<br>4,860[c] | 9,25,36,61<br>8<br>29 | 1.6-2.4 | 8,29 | | |
| *Libocedrus decurrens* | Incense cedar | | | .6 | 53 | | |
| *Picea englemannii* | Englemann spruce | 8,420-9,616<br>8,359[d] | 9,25,36,61<br>8 | 2.5-2.6 | 8,29 | | |
| *Picea glauca* | White spruce | 8,340-8,913 | 25,52 | 3.0-4.2 | 29,52 | 52.4 (C)<br>6.4 (H)<br>38.1 (O)<br>.1 (N)<br>0 (S) | 52 |
| *Picea mariana* | Black spruce | 8,377 | 77 | .27-.46<br>2.0 | 77<br>8 | 46.4 (C)<br>5.9 (H)<br>.19 (N) | 77 |

**Table 5—Higher heating values and ash content of northwestern conifers (bark) (continued)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon Hydrogen Oxygen Nitrogen Sulfur | Citation number |
| | | *Btu/OD lb* | | *Percent* | | *Percent* | |
| *Picea pungens* | Blue spruce | | | | | | |
| *Picea sitchensis* | Sitka spruce | | | | | | |
| *Pinus albicaulis* | Whitebark pine | | | | | | |
| *Pinus aristata* | Bristlecone pine | | | | | | |
| *Pinus attenuata* | Knobcone pine | | | | | | |
| *Pinus contorta* | Lodgepole pine | 9,310-10,760 | 9,16,25,31,36 | .5-2.2 | 8,29,31 | 55.0 (C) | 31 |
| | | 10,190[e] | 8 | | | 5.8 (H) | |
| | | | | | | 38.7 (O+N) | |
| | | | | | | trace (S) | |
| *Pinus jeffreyi* | Jeffrey pine | | | | | | |
| *Pinus lambertiana* | Sugar pine | | | .6 | 8 | | |
| *Pinus monticola* | Western white pine | 8,904-9,335 | 21,27,36 | 1.3-2.6 | 21,27 | | |
| | | 5,040[c] | 29 | | | | |
| *Pinus muricata* | Bishop pine | 9,415-9,616 | 25,36,89 | .7 | 29,53 | | |
| *Pinus ponderosa* | Ponderosa pine | | | | | | |
| *Pinus radiata* | Monterey pine | | | | | | |
| *Pinus sabiniana* | California foothill pine | | | | | | |
| *Pseudotsuga menziesii* | Douglas-fir | | | | | 51.2-56.2 (C) | 9,14,31,38 |
| | | | | | | 5.8-6.2 (H) | 9,14,31,38 |
| | Old growth | 10,100 | 92 | 2.2 | 53 | 38.8-39.3 (O) | 9,14,38 |
| | Second growth | 10,150 | 92 | 1.2 | 53 | 0-.2 (N) | 9,14,38 |
| | At test | 9,373-10,845 | 9,14,16,21,25, 31,36,60,89 | 1.0-3.7 | 9,14,21,29, 31,38,41 | 36.7 (O+N) | 31 |
| | | | | | | 0.0-trace (S) | 9,14,31,38 |

**Table 5—Higher heating values and ash content of northwestern conifers (bark) (continued)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon Hydrogen Oxygen Nitrogen Sulfur | Citation number |
| | | *Btu/OD lb* | | *Percent* | | *Percent* | |
| *Sequoia sempervirens* | Redwood | 8,350 | 2 | .4-.8 | 2,31,53 | 51.9 (C)<br>5.1 (H)<br>42.4 (O)<br>42.6 (O+N)<br>.1 (N)<br>trace-.1 (S) | 2,3<br>2<br>2<br>31<br>2<br>2,31 |
| *Sequoiadendron giganteum* | Giant sequoia | | | | | | |
| *Taxus brevifolia* | Pacific yew | 6,961 | 21 | 8.1 | 21 | | |
| *Thuja plicata* | Western redcedar | 8,694-9,014<br>4,830[c] | 9,16,21,36,60<br>29 | 1.95-2.25 | 21,29,53 | | |
| *Tsuga heterophylla* | Western hemlock | 8,900-9,943 | 9,14,16,21,25, 29,36,60 | 1.5-3.7 | 9,14,21,29 | 51.2-53.0 (C)<br>5.8-6.2 (H)<br>39.2-39.3 (O)<br>0-.1 (N)<br>0-trace (S) | 9,14 |
| *Tsuga mertensiana* | Mountain hemlock | | | | | | |

[a] Ash content on oven-dry basis.
[b] British thermal units per pound, at 6.7 percent moisture content.
[c] Kilocalories per kilogram; moisture content not stated.
[d] British thermal units per pound, at 5.5 percent moisture content.
[e] British thermal units per pound, at 5.6 percent moisture content.

**Table 6—Higher heating values and ash content of northwestern conifers (bark) in International System of Units (SI)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon Hydrogen Oxygen Nitrogen Sulfur | Citation number |
| | | *Megajoule per kilogram* | | *Percent* | | *Percent* | |
| *Abies amabilis* | Pacific silver fir | | | | | | |
| *Abies concolor* | White fir | | | | | | |
| *Abies grandis* | Grand fir | 22.42 | 36 | 1.25 | 53 | | |
| *Abies lasiocarpa* | Subalpine fir | | | | | | |
| *Abies magnifica* | California red fir | | | 1.3 | 53 | | |
| *Abies procera* | Noble fir | | | | | | |
| *Chamaecyparis lawsoniana* | Port Orford cedar | | | | | | |
| *Chamaecyparis nootkatensis* | Alaska yellow-cedar | | | | | | |
| *Juniperus occidentalis* | Western juniper | | | | | | |
| *Larix occidentalis* | Western larch | 19.26-21.31<br>19.08<br>20.35 | 9,25,36,61<br>8<br>29 | .8-1.2 | 8,29 | | |
| *Libocedrus decurrens* | Incense cedar | | | .3 | 53 | | |
| *Picea englemannii* | Englemann spruce | 19.58-22.37<br>19.44 | 9,25,36,61<br>8 | 1.25-1.3 | 8,29 | | |
| *Picea glauca* | White spruce | 19.40-20.73 | 25,52 | 1.5-2.1 | 29,52 | 52.4 (C)<br>6.4 (H)<br>38.1 (O)<br>.1 (N)<br>0 (S) | 52 |
| *Picea mariana* | Black spruce | 19.48 | 77 | .135-.23<br>1.0 | 77<br>8 | 46.4 (C)<br>5.9 (H)<br>.19 (N) | 77 |
| *Picea pungens* | Blue spruce | | | | | | |
| *Picea sitchensis* | Sitka spruce | | | | | | |

**Table 6—Higher heating values and ash content of northwestern conifers (bark) in International System of units (SI) (continued)**

| Scientific name | Common name | Heating value: Value | Heating value: Citation number | Analysis: Ash[a] | Analysis: Citation number | Analysis: Carbon Hydrogen Oxygen Nitrogen Sulfur | Analysis: Citation number |
|---|---|---|---|---|---|---|---|
| | | *Megajoule per kilogram* | | *Percent* | | *Percent* | |
| *Pinus albicaulis* | Whitebark pine | | | | | | |
| *Pinus aristata* | Bristlecone pine | | | | | | |
| *Pinus attenuata* | Knobcone pine | | | | | | |
| *Pinus contorta* | Lodgepole pine | 21.66-25.03 | 9,16,25,31,36 | .25-1.1 | 8,29,31 | 55.0 (C) | 31 |
| | | 23.70 | 8 | | | 5.8 (H) | |
| | | | | | | 38.7 (O+N) | |
| | | | | | | trace (S) | |
| *Pinus jeffreyi* | Jeffrey pine | | | | | | |
| *Pinus lambertiana* | Sugar pine | | | .3 | 8 | | |
| *Pinus monticola* | Western white pine | 20.71-21.71 | 21,27,36 | .65-1.3 | 21,27 | | |
| | | 21.10 | 29 | | | | |
| *Pinus muricata* | Bishop pine | 21.90-22.37 | 25,36,89 | .35 | 29,53 | | |
| *Pinus ponderosa* | Ponderosa pine | | | | | | |
| *Pinus radiata* | Monterey pine | | | | | | |
| *Pinus sabiniana* | California foothill pine | | | | | | |
| *Pseudotsuga menziesii* | Douglas-fir | | | | | 51.2-56.2 (C) | 9,14,31,38 |
| | | | | | | 5.8-6.2 (H) | 9,14,31,38 |
| | Old growth | 23.49 | 92 | 1.1 | 53 | 38.8-39.3 (O) | 9,14,38 |
| | Second growth | 23.61 | 92 | .6 | 53 | 0-.2 (N) | 9,14,38 |
| | At test | 21.80-25.23 | 9,14,16,21,25, 31,36,60,89 | .5-1.85 | 9,14,21,29, 31,38,41 | 36.7 (O+N) | 31 |
| | | | | | | 0-trace (S) | 9,14,31,38 |

**Table 6—Higher heating values and ash content of northwestern conifers (bark) in International System of units (SI) (continued)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon<br>Hydrogen<br>Oxygen<br>Nitrogen<br>Sulfur | Citation number |
| | | *Megajoule per kilogram* | | *Percent* | | *Percent* | |
| *Sequoia sempervirens* | Redwood | 19.42 | 2 | .2-.4 | 2,31,53 | 51.9 (C)<br>5.1 (H)<br>42.4 (O)<br>42.6 (O+N)<br>.1 (N)<br>trace-.1 (S) | 2,31<br>2,31<br>2<br>31<br>2<br>2,31 |
| *Sequoiadendron giganteum* | Giant sequoia | | | | | | |
| *Taxus brevifolia* | Pacific yew | 16.19 | 21 | 4.05 | 21 | | |
| *Thuja plicata* | Western redcedar | 20.22-20.97<br>20.22 | 9,16,21,36,60<br>29 | .975-1.125 | 21,29,53 | | |
| *Tsuga heterophylla* | Western hemlock | 20.70-23.13 | 9,14,16,21,25,<br>29,36,60 | .75-1.85 | 9,14,21,29 | 51.2-53.0 (C)<br>5.8-6.2 (H)<br>39.2-39.3 (O)<br>0-.1 (N)<br>0-trace (S) | 9,14 |
| *Tsuga mertensiana* | Mountain hemlock | | | | | | |

[a] Ash content on total weight or green basis. This value was calculated by assuming an increase in mass from oven-dry to 50-percent moisture content green basis. This mass increase would all be water and the amount of ash would remain the same (e.g., doubling the number of pounds of mass in relation to the ash). Thus, to get the ash content on green basis, the value for the oven-dry basis is divided by half. Actual moisture content of green material may differ from a moisture content of 50-percent green basis.

**Table 7—Higher heating values and ash content of northwestern conifers (wood)**

| Scientific name | Common name | By volume: Value | By volume: Citation number | By weight: Value | By weight: Citation number | Ash: Value | Ash: Citation number |
|---|---|---|---|---|---|---|---|
| | | *Million Btu per AD cord* | | *Btu/OD lb* | | *Percent* | |
| *Abies amabilis* | Pacific silver fir | 16.5 | 24 | | | 0.23-0.47 | 6,29,64 |
| *Abies concolor* | White fir | | | 8,795 | 89 | .4-.85 | 29,64,83 |
| | | | | 4,440[a] | 29 | | |
| *Abies grandis* | Grand fir | 17.4 | 24 | 8,664 | 89 | .25-.49 | 18,42,64 |
| *Abies lasiocarpa* | Subalpine fir | | | | | .4-.5 | 64,83 |
| *Abies magnifica* | California red fir | | | | | .30 | 64 |
| *Abies procera* | Noble fir | | | | | .34-.71 | 29,42,64 |
| *Chamaecyparis lawsoniana* | Port Orford cedar | | | | | .10 | 64 |
| *Chamaecyparis nootkatensis* | Alaska yellow-cedar | | | 9,900 | 16 | .22-.34 | 42,64 |
| *Juniperus occidentalis* | Western juniper | | | | | .12-.36 | 40,64 |
| *Larix occidentalis* | Western larch | 26.5 | 24 | 8,370-8,431 | 21,36 | .09-.80 | 21,29,61,64,83 |
| *Libocedrus decurrens* | Incense cedar | | | | | | |
| | Sapwood | | | | | .47 | 29 |
| | Heartwood | | | 10,668 | 89 | .30 | 29 |
| | Mixed | | | | | .08-.34 | 29,64 |
| *Picea englemannii* | Englemann spruce | 17.6 | 24 | | | .20-2.0 | 29,61,64,83 |
| *Picea glauca* | White spruce | 16.2 | 24 | 8,890 | 78 | .22-.30 | 10,29 |
| *Picea mariana* | Black spruce | 19.1 | 24 | 8,377-8,551 | 77 | | 77 |
| | | | | 8,246 | 8 | | |
| *Picea pungens* | Blue spruce | | | | | .38 | 64 |
| *Picea sitchensis* | Sitka spruce | 15.9 | 24 | 8,100 | 16 | .17-.45 | 29,64 |
| | | | | 4,500[a] | 29 | | |
| *Pinus albicaulis* | Whitebark pine | | | | | .27 | 64 |
| *Pinus aristata* | Bristlecone pine | | | | | .30 | 64 |
| *Pinus attenuata* | Knobcone pine | | | | | .20-.33 | 43,64 |
| *Pinus contorta* | Lodgepole pine | | | | | | |
| | Sapwood | | | | | | |
| | Green | | | 19.9[b] | 44 | .36 | 44 |
| | Dead down | | | 19.5[b] | 44 | .51 | 44 |
| | Dead standing | | | 19.6[b] | 44 | .53 | 44 |

Table 7—Higher heating values and ash content of northwestern conifers (wood) (continued)

| Scientific name | Common name | By volume Value | By volume Citation number | By weight Value | By weight Citation number | Ash Value | Ash Citation number |
|---|---|---|---|---|---|---|---|
| | | *Million Btu per AD cord* | | *Btu/OD lb* | | *Percent* | |
| | Heartwood | | | | | | |
| | Green | | | 20.0 [b] | 44 | .34 | 44 |
| | Dead down | | | 19.9 [b] | 44 | .43 | 44 |
| | Dead standing | | | 20.1 [b] | 44 | .55 | 44 |
| | Mixed | 20.1 | 24 | 8,600 | 16 | | |
| | | | | 4,870 [a] | 29 | | |
| | Mixed (at test) | | | | | .19-.50 | 29,42,44,61,64,82 |
| *Pinus jeffreyi* | Jeffrey pine | | | | | .26 | 64 |
| *Pinus lambertiana* | Sugar pine | | | | | | |
| | Sapwood | | | | | .20 | 29 |
| | Heartwood | | | | | .20 | 29 |
| | Mixed | | | | | .22-.50 | 61,64 |
| *Pinus monticola* | Western white pine | | | | | | |
| | Sapwood | | | | | | |
| | Green | | | 19.8 [b] | 44 | .29 | 44 |
| | Dead down | | | 19.8 [b] | 44 | .29 | 44 |
| | Dead standing | | | 19.5 [b] | 44 | .23 | 44 |
| | At test | | | | | .20 | 29 |
| | Heartwood | | | | | | |
| | Green | | | 20.3 [b] | 44 | .36 | 44 |
| | Dead down | | | 20.4 [b] | 44 | .28 | 44 |
| | Dead standing | | | 20.2 [b] | 44 | .30 | 44 |
| | At test | | | | | .20 | 29 |
| | Mixed | 18.6 | 24 | 8,366-8,620 | 21,35 | | |
| | Mixed (at test) | | | | | .20-.33 | 21,29,44,64,82 |
| *Pinus muricata* | Bishop pine | | | | | .26 | 64 |
| *Pinus ponderosa* | Ponderosa pine | | | | | | |
| | Sapwood | | | | | .30 | 29 |
| | Heartwood | | | 8,920-8,992 | 89 | .20 | 29 |
| | Mixed | 22.1 | 24 | 9,100-9,140 | 9,16,29,92 | .18-.50 | 29,53,61,64,82 |
| *Pinus radiata* | Monterey pine | | | | | .30 | 64 |
| *Pinus sabiniana* | California foothill pine | | | | | 1.10-.40 | 43,64 |

**Table 7—Higher heating values and ash content of northwestern conifers (wood) (continued)**

| Scientific name | Common name | By volume Value | By volume Citation number | By weight Value | By weight Citation number | Ash Value | Ash Citation number |
|---|---|---|---|---|---|---|---|
| | | *Million Btu per AD cord* | | *Btu/OD lb* | | *Percent* | |
| *Pseudotsuga menziesii* | Douglas-fir | | | | | .08-.80 | 6,15,21,29,40,53, 64,83 |
| | Sapwood | | | 8,500 | 92 | | |
| | Heartwood | | | 7,500-9,000 | 29,89,92 | | |
| | Mixed | 22.2[c] | | 8,318-9,200 | 9,15,16, 21,61,89 | | |
| | Mixed | 24.3 | 24 | | | | |
| *Sequoia sempervirens* | Redwood | | | 8,840-9,220 | 15,60 | | |
| | | | | 5,020[a] | 29 | | |
| | Second growth | | | | | .10 | 83 |
| | Old growth | | | | | .10 | 83 |
| | Mixed | | | | | .14-.40 | 15,29,53,64 |
| *Sequoiadendron giganteum* | Giant sequoia | | | | | .50 | 64 |
| *Taxus brevifolia* | Pacific yew | | | 9,322 | 21 | .22-.32 | 21,40,64 |
| *Thuja plicata* | Western redcedar | 16.8 | 24 | 8,588-9,700 | 16,21,92 | .27-.42 | 21,35,29 |
| *Tsuga heterophylla* | Western hemlock | 19.3 | 24 | 8,410-8,620 | 9,15,16,21,92 | | |
| | Sapwood | | | | | .37 | 29 |
| | Heartwood | | | | | .51 | 29 |
| | Mixed | | | | | .30-2.2 | 15,21,29,35,83 |
| *Tsuga mertensiana* | Mountain hemlock | | | | | .50 | 29 |

Note: AD = air-dry, OD = oven-dry.

[a] Kilocalories per kilogram (kcal/kg).

[b] Megajoules per kilogram (mJ/kg).

[c] No citation was listed in the original publication.

**Table 8—Higher heating values and ash content of northwestern conifers (wood) in International System of units (SI)**

| | | By volume | | By weight | | Ash[a] | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value[b] | Citation number | Value | Citation number | Value | Citation number |
| | | *Megajoules per solid AD cubic meter* | | *Megajoules per kilogram* | | *Percent* | |
| *Abies amabilis* | Pacific silver fir | 6822.3 | 24 | | | 0.115-0.235 | 6,29,64 |
| *Abies concolor* | White fir | | | 20.46 | 89 | .2-.425 | 29,64,83 |
| | | | | 18.59 | 29 | | |
| *Abies grandis* | Grand fir | 7194.4 | 24 | 20.15 | 89 | .125-.245 | 18,42,64 |
| *Abies lasiocarpa* | Subalpine fir | | | | | .2-.25 | 64,83 |
| *Abies magnifica* | California red fir | | | | | .15 | 64 |
| *Abies procera* | Noble fir | | | | | .17-.355 | 29,42,64 |
| *Chamaecyparis lawsoniana* | Port Orford cedar | | | | | .05 | 64 |
| *Chamaecyparis nootkatensis* | Alaska yellow-cedar | | | 23.03 | 16 | .11-.17 | 42,64 |
| *Juniperus occidentalis* | Western juniper | | | | | .06-.18 | 40,64 |
| *Larix occidentalis* | Western larch | 10 957.0 | 24 | 19.47-19.61 | 21,36 | .045-.40 | 21,29,61,64,83 |
| *Libocedrus decurrens* | Incense cedar | | | | | | |
| | Sapwood | | | | | .235 | 29 |
| | Heartwood | | | 24.81 | 89 | .15 | 29 |
| | Mixed | | | | | .04-.17 | 29,64 |
| *Picea englemannii* | Englemann spruce | 7277.1 | 24 | | | .10-1.0 | 29,61,64,83 |
| *Picea glauca* | White spruce | 6698.2 | 24 | 20.68 | 78 | .11-.15 | 10,29 |
| *Picea mariana* | Black spruce | 7897.3 | 24 | 19.48-19.89 | 77 | .195 | 77 |
| | | | | 19.18 | 8 | | |
| *Picea pungens* | Blue spruce | | | | | .19 | 64 |
| *Picea sitchensis* | Sitka spruce | 6574.2 | 24 | 18.84 | 16 | .085-.225 | 29,64 |
| *Pinus albicaulis* | Whitebark pine | | | | | .135 | 64 |
| *Pinus aristata* | Bristlecone pine | | | | | .15 | 64 |
| *Pinus attenuata* | Knobcone pine | | | | | .10-.165 | 43,64 |
| *Pinus contorta* | Lodgepole pine | | | | | | |
| | Sapwood | | | | | | |
| | Green | | | 19.9 | 44 | .18 | 44 |
| | Dead down | | | 19.5 | 44 | .255 | 44 |
| | Dead standing | | | 19.6 | 44 | .265 | 44 |

Table 8—Higher heating values and ash content of northwestern conifers (wood) in International System of Units (SI) (continued)

| Scientific name | Common name | By volume: Value[b] | By volume: Citation number | By weight: Value | By weight: Citation number | Ash[a]: Value | Ash[a]: Citation number |
|---|---|---|---|---|---|---|---|
| | | *Megajoules per solid AD cubic meter* | | *Megajoules per kilogram* | | *Percent* | |
| | Heartwood | | | | | | |
| | Green | | | 20.0 | 44 | .17 | 44 |
| | Dead down | | | 19.9 | 44 | .215 | 44 |
| | Dead standing | | | 20.1 | 44 | .275 | 44 |
| | Mixed | 8310.8 | 24 | 20.00 | 16 | | |
| | Mixed | | | 20.39 | 29 | | |
| | Mixed (at test) | | | | | .095-.25 | 29,42,44,61,64, 82,64 |
| *Pinus jeffreyi* | Jeffrey pine | | | | | .13 | |
| *Pinus lambertiana* | Sugar pine | | | | | | |
| | Sapwood | | | | | .10 | 29 |
| | Heartwood | | | | | .10 | 29 |
| | Mixed | | | | | .11-.25 | 61,64 |
| *Pinus monticola* | Western white pine | | | | | | |
| | Sapwood | | | | | | |
| | Green | | | 19.8 | 44 | .145 | 44 |
| | Dead down | | | 19.8 | 44 | .145 | 44 |
| | Dead standing | | | 19.5 | 44 | .115 | 44 |
| | At test | | | | | .10 | 29 |
| | Heartwood | | | | | | |
| | Green | | | 20.3 | 44 | .18 | 44 |
| | Dead down | | | 20.4 | 44 | .14 | 44 |
| | Dead standing | | | 20.2 | 44 | .15 | 44 |
| | At test | | | | | .10 | 29 |
| | Mixed | 7690.6 | 24 | 19.46-20.05 | 21,35 | | |
| | Mixed (at test) | | | | | .10-.165 | 21,29,44,64,82 |
| *Pinus muricata* | Bishop pine | | | | | .13 | 64 |
| *Pinus ponderosa* | Ponderosa pine | | | | | | |
| | Sapwood | | | | | .15 | 29 |
| | Heartwood | | | 20.75-20.92 | 89 | .10 | 29 |
| | Mixed | 9137.7 | 24 | 21.17-21.26 | 9,16,29,92 | .09-.25 | 29,53,61,64,82 |
| *Pinus radiata* | Monterey pine | | | | | .15 | 64 |

**Table 8—Higher heating values and ash content of northwestern conifers (wood) in International System of Units (SI) (continued)**

| | | By volume | | By weight | | Ash[a] | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value[b] | Citation number | Value | Citation number | Value | Citation number |
| | | *Megajoules per solid AD cubic meter* | | *Megajoules per kilogram* | | *Percent* | |
| *Pinus sabiniana* | California foothill pine | | | | | .55-.20 | 43,64 |
| *Pseudotsuga menziesii* | Douglas-fir | | | | | .04-.40 | 6,15,21,29,40,53, 64,83 |
| | Sapwood | | | 19.77 | 92 | | |
| | Heartwood | | | 17.44-20.93 | 29,89,92 | | |
| | Mixed | 9179.0[c] | | 19.35-21.40 | 9,15,16,21, 61,89 | | |
| | Mixed | 10 047.3 | 24 | | | | |
| *Sequoia sempervirens* | Redwood | | | 20.56-21.45 | 15,60 | | |
| | | | | 21.02 | 29 | | |
| | Second growth | | | | | .05 | 83 |
| | Old growth | | | | | .05 | 83 |
| | Mixed | | | | | .07-.20 | 15,29,53,64 |
| *Sequoiadendron giganteum* | Giant sequoia | | | | | .25 | 64 |
| *Taxus brevifolia* | Pacific yew | | | 21.68 | 21 | .11-.16 | 21,40,64 |
| *Thuja plicata* | Western redcedar | 6946.3 | 24 | 19.98-22.56 | 16,21,92 | .135-.21 | 21,35,29 |
| *Tsuga heterophylla* | Western hemlock | 7980.0 | 24 | 19.56-20.05 | 9,15,16,21,92 | | |
| | Sapwood | | | | | .185 | 29 |
| | Heartwood | | | | | .255 | 29 |
| | Mixed | | | | | .15-1.1 | 15,21,29,35,83 |
| *Tsuga mertensiana* | Mountain hemlock | | | | | .25 | 29 |

[a] Ash content on total weight or green basis. This value was calculated by assuming an increase in mass from oven-dry to 50-percent moisture content green basis. This mass increase would all be water and the amount of ash would remain the same (e.g., doubling the number of pounds of mass in relation to the ash). Thus, to get the ash content on green basis, the value for the oven-dry basis is divided by half. Actual moisture content of green material may differ from a moisture content of 50-percent green basis.

[b] The conversion to standard international units was made by multiplying the value of British thermal units by 1054.35 to get the value of megajoules. This number was then divided by 2.55 to convert from a cord to cubic meters of solid material. One cord contains 3.62 $m^3$, based on 90 $ft^3$ of solid material. AD = air-dry.

[c] No citation was listed in the original publication.

## Hardwoods

The data for northwestern hardwoods listed below are presented in six tables. The physical properties are given in table 9 for the bark and table 10 for the wood. Table 11 provides the heating values, ash content, and analysis of the bark of the hardwoods as per the original publication. Table 12 provides these same properties but converted into metric units and ash content on wet basis. Table 13 provides the heating values and ash content of the wood of the hardwood species. Like table 12, table 14 shows the data converted into metric units and ash content on wet basis.

## Hardwood species

| Scientific name | Common name |
|---|---|
| *Acer macrophyllum* Pursh | Bigleaf maple |
| *Alnus rhombifolia* Nutt. | White alder |
| *Alnus rubra* Bong. | Red alder |
| *Arbutus menziesii* Pursh | Pacific madrone |
| *Betula papyrifera* Marsh. | Paper birch |
| *Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmqvist | Giant chinquapin, golden chinquapin |
| *Castanopsis chrysophylla* (Douglas ex Hook.) Hjelmqvist var. *chrysophylla* | Giant chinquapin, golden chinquapin |
| *Cornus nuttallii* Audubon ex Torr. & A. Gray | Pacific dogwood |
| *Fraxinus latifolia* Benth. | Oregon ash |
| *Lithocarpus densiflorus* (Hook. & Arn.) Rehder | Tanoak |
| *Populus balsamifera* L. ssp. *trichocarpa* (Torr. & A. Gray ex Hook.) Brayshaw | Black cottonwood |
| *Populus fremontii* S. Watson | Fremont cottonwood |
| *Populus tremuloides* Michx. | Quaking aspen |
| *Populus trichocarpa* Torr. & A. Gray ex Hook. | Black cottonwood |
| *Quercus agrifolia* Nee | California coastal live oak |
| *Quercus chrysolepis* Liebm. | Canyon live oak |
| *Quercus douglasii* Hook. & Arn. | Blue oak |
| *Quercus garryana* Douglas ex Hook. | Oregon white oak |
| *Quercus kelloggii* Newberry | California black oak |
| *Quercus lobata* Nee | Valley oak, California white oak |
| *Quercus wislizeni* A. DC. | Interior live oak |
| *Umbellularia californica* (Hook. & Arn.) Nutt. | California laurel, Oregon myrtle, California bay |

**Table 9—Physical properties of northwestern hardwoods (bark)**

| | | Specific gravity | | Moisture content | | | Bark by volume | |
|---|---|---|---|---|---|---|---|---|
| **Scientific name** | **Common name** | **Value**[a] | **Citation number** | **Oven-dry basis** | **Total-weight basis** | **Citation number** | **Value** | **Citation number** |
| | | | | – – – – – *Percent* – – – – – | | | *Percent* | |
| *Acer macrophyllum* | Bigleaf maple | | | | | | 7.8-10.5 | 16,21 |
| | Inner bark | 0.66 | 73 | 134 | 57 | 73 | | |
| | Outer bark | .45 | 73 | 70.1 | 41.2 | 73 | | |
| | Mixed | .56 | 21 | 60.5 | 37.7 | 21 | | |
| | Mixed | .55[b] | 27 | | | | | |
| *Alnus rhombifolia* | White alder | | | | | | | |
| *Alnus rubra* | Red alder | | | | | | 13.5 | 16 |
| | Inner bark | .52 | 73 | 87.8 | 46.8 | 73 | | |
| | Outer bark | .62 | 73 | 66.0 | 39.8 | 73 | | |
| | Mixed | .58 | 26 | | | | | |
| *Arbutus menziesii* | Pacific madrone | | | | | | | |
| *Betula papyrifera* | Paper birch | | | | | | 8.0-15.7 | 16,74,84 |
| | Inner bark | .57-.63 | 30,73 | 67.7 | 40.4 | 73 | | |
| | Outer bark | .54-.66 | 30,73 | 22.5 | 18.4 | 73 | | |
| | Mixed | .56 | 30 | | | | | |
| | Mixed | .69[b] | 27 | | | | | |
| *Castanopsis chrysophylla* | Giant chinquapin | | | | | | 11.1 | 84 |
| *Cornus nuttallii* | Pacific dogwood | | | | | | | |
| *Fraxinus latifolia* | Oregon ash | .50[b] | 27 | | | | | |
| *Lithocarpus densiflorus* | Tanoak | .75[b] | 27 | | | | 15.7 | 81 |
| *Populus fremontii* | Fremont cottonwood | | | | | | | |
| *Populus tremuloides* | Quaking aspen | | | 65.1-67.2 | 39.4-40.2 | 48 | 8.9-16.5 | 16,48,81 |
| | Inner bark | .4 | 30 | | | | | |
| | Outer bark | .55 | 30 | | | | | |
| | Mixed | .50 | 25,30 | | | | | |
| | Mixed | .61-.73[b] | 27 | | | | | |

**Table 9—Physical properties of northwestern hardwoods (bark) (continued)**

| Scientific name | Common name | Specific gravity: Value[a] | Specific gravity: Citation number | Moisture content: Oven-dry basis | Moisture content: Total-weight basis | Moisture content: Citation number | Bark by volume: Value | Bark by volume: Citation number |
|---|---|---|---|---|---|---|---|---|
| | | | | Percent | Percent | | Percent | |
| *Populus tricocarpa* | Black cottonwood | | | | | | 18.3 | 16 |
| | Inner bark | .38-.41 | 30,73 | 130 | 57 | 73 | | |
| | Outer bark | .42-.44 | 30,73 | 77.4 | 43.6 | 73 | | |
| | Mixed | .40-.46 | 26,30,74 | | | | | |
| | Mixed | .60[b] | 27 | | | | | |
| *Quercus agrifolia* | California coastal live oak | | | | | | | |
| *Quercus chrysolepis* | Canyon live oak | | | | | | | |
| *Quercus douglasii* | Blue oak | | | | | | | |
| *Quercus garryana* | Oregon white oak | .80[b] | 27 | | | | | |
| *Quercus kelloggii* | California black oak | | | | | | | |
| *Quercus lobata* | Valley oak | .66[b] | 27 | | | | | |
| *Quercus wislizeni* | Interior live oak | | | | | | | |
| *Umbellularia californica* | California laurel | | | | | | | |

[a] Green volume, oven-dry weight unless otherwise noted.

[b] Oven-dry volume, oven-dry weight.

**Table 10—Physical properties of northwestern hardwoods (wood)**

| | | Specific gravity | | Moisture content | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sapwood | | | Heartwood | | | Mixed or unspecified | | |
| Scientific name | Common name | Value[a] | Citation number | OD basis | TW basis | Citation number | OD basis | TW basis | Citation number | OD basis | TW basis | Citation number |
| | | | | – – *Percent* – – | | | – – *Percent* – – | | | – – *Percent*– – | | |
| *Acer macrophyllum* | Bigleaf maple | 0.44-0.62 | 20,21,49 | | | | | | | 39-72 | 28-42 | 16,20,21,49 |
| *Alnus rhombifolia* | White alder | .41[b] | 64 | | | | | | | | | |
| *Alnus rubra* | Red alder | .37-.41 | 20,49,81 | 97 | 49 | 57 | | | | 98-101 | 49-50 | 16,20,49 |
| *Arbutus menziesii* | Pacific madrone | .54-.58 | 49,65,80 | | | | | | | 68-93 | 40-48 | 49,57,65,80 |
| *Betula papyrifera* | Paper (white) birch | 48-.52 | 16,20,37, 49,84 | 72 | 42 | 16,57 | 74-89 | 43-47 | 16,57 | 65-73 | 39-42 | 16,20,49 |
| *Castanopsis chrysoplylla* | Giant chinquapin | | | | | | | | | 111-166 | 53-62 | 49,57,63,80 |
| | Sapwood | .40-.41 | 63 | | | | | | | | | |
| | Heartwood | .42 | 63 | | | | | | | | | |
| | Mixed | .41-.43 | 49,63,80,84 | | | | | | | | | |
| *Cornus nuttallii* | Pacific dogwood | .58 | 49 | | | | | | | 52 | 34 | 49 |
| *Fraxinus latifolia* | Oregon ash | .50 | 49 | | | | | | | 48 | 32 | 49 |
| *Lithocarpus densiflorus* | Tanoak | .48-.62 | 19,54,62, 67,80,81,86 | | | | | | | 43.6-120 | 30.4-55 | 19,54,57, 62,67,80,86 |
| *Populus fremontii* | Fremont cottonwood | .41 | 17 | | | | | | | 139 | 58 | 17 |
| *Populus tremuloides* | Quaking aspen | .33-.39 | 20,37,49,81 | 113 | 53 | 57 | 95 | 49 | 57 | 90-123 | 47-55 | 20,46,48,49 |
| *Populus trichocarpa* | Black cottonwood | .28-.40 | 37,47,49 | 146 | 59 | 57 | 162 | 62 | 57 | 132-175 | 57-64 | 16,49 |
| *Quercus agrifolia* | California coastal live oak | .83[b] | 64 | | | | | | | | | |
| *Quercus chrysolepis* | Canyon live oak | .70 | 49 | | | | | | | 62 | 38 | 49 |
| *Quercus douglasii* | Blue oak | .64 | 81 | | | | | | | | | |
| *Quercus garryana* | Oregon white oak | .63-.64 | 49,55 | | | | | | | 67-72 | 40-42 | 49,55 |
| *Quercus kelloggii* | California black oak | .46-.51 | 49,66,81 | 75 | 43 | 57 | 76 | 43 | 57 | 106-108 | 51-52 | 49,66 |
| *Quercus lobata* | Valley oak | .53-.58 | 55,69,81 | | | | | | | 91-103 | 48-51 | 55,69 |
| *Quercus wislizeni* | Interior live oak | .79[b] | 64 | | | | | | | | | |
| *Umbellularia californica* | California laurel | .51-.59 | 49,80 | | | | | | | 59.8-70 | 37.4-41 | 49,57,80 |

Note: OD = oven-dry, TW = total weight.

[a] Green volume, oven-dry weight unless otherwise noted.

[b] Oven-dry volume, oven-dry weight.

**Table 11—Higher heating values and ash content of northwestern hardwoods (bark)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon Hydrogen Oxygen Nitrogen Sulfur | Citation number |
| | | *Btu/OD lb* | | *Percent* | | *Percent* | |
| *Acer macrophyllum* | Bigleaf maple | 8,277 | 21 | 6.9 | 21 | | |
| *Alnus rhombifolia* | White alder | | | | | | |
| *Alnus rubra* | Red alder | 8,406-8,760<br>7,947[b] | 9,26,60<br>8 | 2.4-5.9 | 8,30,61 | 46.03 (C)<br>5.94 (H)<br>.6 (N) | 77 |
| *Arbutus menziesii* | Pacific madrone | | | | | | |
| *Betula papyrifera* | Paper birch | 9,490-<br>10,310<br>9,434[c] | 9,52<br><br>8 | 1.5-2.4 | 8,30,52 | 57.4 (C)<br>6.7 (H)<br>33.8 (O)<br>.3 (N)<br>0 (S) | 52 |
| *Castanopsis chrysophylla* | Giant chinquapin | | | | | | |
| *Cornus nuttallii* | Pacific dogwood | | | | | | |
| *Fraxinus latifolia* | Oregon ash | | | | | | |
| *Lithocarpus densiflorus* | Tanoak | | | | | | |
| *Populus fremontii* | Fremont cottonwood | | | | | | |
| *Populus tremuloides* | Quaking aspen | 8,430-8,712<br>8,433[d] | 9,25,30<br>8 | 2.8 | 8 | | |

**Table 11—Higher heating values and ash content of northwestern hardwoods (bark) (continued)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon Hydrogen Oxygen Nitrogen Sulfur | Citation number |
| | | *Btu/OD lb* | | *Percent* | | *Percent* | |
| *Populus trichocarpa* | Black cottonwood | 8,765-9,000 | 16,26,60 | 5.0 | 30 | | |
| *Quercus agrifolia* | California coastal live oak | | | | | | |
| *Quercus chrysolepis* | Canyon live oak | | | | | | |
| *Quercus douglasii* | Blue oak | | | | | | |
| *Quercus garryana* | Oregon white oak | | | | | | |
| *Quercus kelloggii* | California black oak | | | | | | |
| *Quercus lobata* | Valley oak | | | | | | |
| *Quercus wislizeni* | Interior live oak | | | | | | |
| *Umbellularia caifornica* | California laurel | | | | | | |

[a] Ash content on oven-dry basis.

[b] British thermal units per pound, at 5.8 percent moisture content.

[c] British thermal units per pound, at 4.8 percent moisture content.

[d] British thermal units per pound, at 5.5 percent moisture content.

Table 12—Higher heating values and ash content of northwestern hardwoods (bark) in International System of units (SI)

| Scientific name | Common name | Heating value: Value | Heating value: Citation number | Analysis: Ash[a] | Analysis: Citation number | Analysis: Carbon Hydrogen Oxygen Nitrogen Sulfur | Analysis: Citation number |
|---|---|---|---|---|---|---|---|
| | | *Megajoules per kilogram* | | *Percent* | | *Percent* | |
| *Acer macrophyllum* | Bigleaf maple | 19.25 | 21 | 3.45 | 21 | | |
| *Alnus rhombifolia* | White alder | | | | | | |
| *Alnus rubra* | Red alder | 19.55-20.38<br>18.48 | 9,26,60<br>8 | 1.2-2.95 | 8,30,61 | 46.03 (C)<br>5.94 (H<br>.6 (N) | 77 |
| *Arbutus menziesii* | Pacific madrone | | | | | | |
| *Betula papyrifera* | Paper birch | 22.07-23.98<br>21.94 | 9,52<br>8 | .75-1.2 | 8,30,52 | 57.4 (C)<br>6.7 (H)<br>33.8 (O)<br>.3 (N)<br>0 (S) | 52 |
| *Castanopsis chrysophylla* | Giant chinquapin | | | | | | |
| *Cornus nuttallii* | Pacific dogwood | | | | | | |
| *Fraxinus latifolia* | Oregon ash | | | | | | |
| *Lithocarpus densiflorus* | Tanoak | | | | | | |
| *Populus fremontii* | Fremont cottonwood | | | | | | |
| *Populus tremuloides* | Quaking aspen | 19.61-20.26<br>19.62 | 9,25,30<br>8 | 1.4 | 8 | | |

**Table 12—Higher heating values and ash content of northwestern hardwoods (bark) in International System of units (SI) (continued)**

| | | Heating value | | Analysis | | | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value | Citation number | Ash[a] | Citation number | Carbon Hydrogen Oxygen Nitrogen Sulfur | Citation number |
| | | *Megajoules per kilogram* | | *Percent* | | *Percent* | |
| *Populus trichocarpa* | Black cottonwood | 20.39-20.93 | 16,26,60 | 2.5 | 30 | | |
| *Quercus agrifolia* | California coastal live oak | | | | | | |
| *Quercus chrysolepis* | Canyon live oak | | | | | | |
| *Quercus douglasii* | Blue oak | | | | | | |
| *Quercus garryana* | Oregon white oak | | | | | | |
| *Quercus kelloggii* | California black oak | | | | | | |
| *Quercus lobata* | Valley oak | | | | | | |
| *Quercus wislizeni* | Interior live oak | | | | | | |
| *Umbellularia caifornica* | California laurel | | | | | | |

[a] Ash content on total weight or green basis. This value was calculated by assuming an increase in mass from oven-dry to 50-percent moisture content green basis. This mass increase would all be water and the amount of ash would remain the same (e.g., doubling the number of pounds of mass in relation to the ash). Thus, to get the ash content on green basis, the value for the oven-dry basis is divided by half. Actual moisture content of green material may differ from a moisture content of 50-percent green basis.

**Table 13—Higher heating values and ash content of northwestern hardwoods (wood)**

| | | By volume | | By weight | | Ash[a] | |
|---|---|---|---|---|---|---|---|
| **Scientific name** | **Common name** | **Value** | **Citation number** | **Value** | **Citation number** | **Value** | **Citation number** |
| | | *Million Btu per AD cord* | | *Btu per OD lb* | | *Percent* | |
| *Acer macrophyllum* | Bigleaf maple | | | 8,140-8,410 | 13,16,21 | 0.26-0.54 | 21,42,64 |
| *Alnus rhombifolia* | White alder | | | | | .31 | 64 |
| *Alnus rubra* | Red alder | 17.4 | 24 | 7,990-8,000 | 9,16 | .23-2.00 | 30,42,61,64 |
| *Arbutus menziesii* | Pacific madrone | | | | | .09-.40 | 40,64 |
| *Betula papyrifera* | Paper birch | 23.4 | 24 | 8,334 | 79 | | |
| | Sapwood | | | | | .24 | 30 |
| | Heartwood | | | | | .21 | 30 |
| | Mixed | | | | | .2-.4 | 30,64,81 |
| *Castanopsis chrysophylla* | Giant chinquapin | | | | | .30-.35 | 42,64 |
| *Cornus nuttallii* | Pacific dogwood | | | | | .22-.50 | 40,64 |
| *Fraxinus latifolia* | Oregon ash | | | 8,200 | 92 | .34 | 64 |
| *Lithocarpus densiflorus* | Tanoak | | | | | .31-1.49 | 42,64,81 |
| *Populus fremontii* | Fremont cottonwood | | | | | .77-1.13 | 64 |
| *Populus tremuloides* | Quaking aspen | 17.7 | 24 | 5,785[b] | 30 | .2-2.1 | 10,30,64,91 |
| | | | | | | .09-.15 (N)[c] | 91 |
| *Populus trichocarpa* | Black cottonwood | 15.5 | 24 | 8,800 | 16 | .3-1.27 | 30,64 |
| *Quercus agrifolia* | California coastal live oak | | | | | 1.28 | 64 |
| *Quercus chrysolepis* | Canyon live oak | | | | | .60 | 64 |
| *Quercus douglasii* | Blue oak | | | | | .84-1.4 | 64,81 |
| *Quercus garryana* | Oregon white oak | | | 8,110 | 13 | .39 | 64 |
| *Quercus kelloggii* | California black oak | | | | | .26-.40 | 64,81 |
| *Quercus lobata* | Valley oak | | | | | .3-.9 | 64,81 |
| *Quercus wislizeni* | Interior live oak | | | | | 1.02 | 64 |
| *Umbellularia californica* | California laurel | | | | | .16-.39 | 40,64 |

Note: AD = air-dry, OD = oven-dry.

[a] Ash content on oven-dry basis.

[b] British thermal units per air-dry pound.

[c] Percentage nitrogen also provided for quaking aspen.

**Table 14—Higher heating values and ash content of northwestern hardwoods (wood) in International System of units (SI)**

| | | By volume | | By weight | | Ash[a] | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value[b] | Citation number | Value | Citation number | Value | Citation number |
| | | *Megajoules per solid AD cubic meter* | | *Megajoules per kilogram* | | *Percent* | |
| *Acer macrophyllum* | Bigleaf maple | | | 18.93-19.56 | 13,16,21 | 0.13-0.27 | 21,42,64 |
| *Alnus rhombifolia* | White alder | | | | | .155 | 64 |
| *Alnus rubra* | Red alder | 7194.4 | 24 | 18.58-18.61 | 9,16 | .115-1.00 | 30,42,61,64 |
| *Arbutus menziesii* | Pacific madrone | | | | | .045-.20 | 40,64 |
| *Betula papyrifera* | Paper birch | 9675.2 | 24 | 19.38 | 79 | | |
| | Sapwood | | | | | .12 | 30 |
| | Heartwood | | | | | .105 | 30 |
| | Mixed | | | | | .1-.2 | 30,64,81 |
| *Castanopsis chrysophylla* | Giant chinquapin | | | | | .15-.175 | 42,64 |
| *Cornus nuttallii* | Pacific dogwood | | | | | .11-.25 | 40,64 |
| *Fraxinus latifolia* | Oregon ash | | | 19.07 | 92 | .17 | 64 |
| *Lithocarpus densiflorus* | Tanoak | | | | | .155-.745 | 42,64,81 |
| *Populus fremontii* | Fremont cottonwood | | | | | .385-.565 | 64 |
| *Populus tremuloides* | Quaking aspen | 7318.4 | 24 | 13.46 | 30 | .1-1.05 | 10,30,64,91 |
| | | | | | | .09-.15 (N)[c] | 91 |
| *Populus trichocarpa* | Black cottonwood | 6408.8 | 24 | 20.47 | 16 | .3-1.27 | 30,64 |
| *Quercus agrifolia* | California coastal live oak | | | | | .64 | 64 |

**Table 14—Higher heating values and ash content of northwestern hardwoods (wood) in International System of units (SI) (continued)**

| | | By volume | | By weight | | Ash[a] | |
|---|---|---|---|---|---|---|---|
| Scientific name | Common name | Value[b] | Citation number | Value | Citation number | Value | Citation number |
| | | *Megajoules per solid AD cubic meter* | | *Megajoules per kilogram* | | *Percent* | |
| *Quercus chrysolepis* | Canyon live oak | | | | | .30 | 64 |
| *Quercus douglasii* | Blue oak | | | | | .42-.7 | 64,81 |
| *Quercus garryana* | Oregon white oak | | | 18.86 | 13 | .195 | 64 |
| *Quercus kelloggii* | California black oak | | | | | .13-.20 | 64,81 |
| *Quercus lobata* | Valley oak | | | | | .15-.45 | 64,81 |
| *Quercus wislizeni* | Interior live oak | | | | | .51 | 64 |
| *Umbellularia californica* | California laurel | | | | | .08-.195 | 40,64 |

[a] Ash content on total weight or green basis. This value was calculated by assuming an increase in mass from oven-dry to 50-percent moisture content green basis. This mass increase would all be water and the amount of ash would remain the same (e.g., doubling the number of pounds of mass in relation to the ash). Thus, to get the ash content on green basis, the value for the oven-dry basis is divided by half. Actual moisture content of green material may differ from a moisture content of 50-percent green basis.

[b] The conversion to standard international units was made by multiplying the value of British thermal units by 1054.35 to get the value of megajoules. This number was then divided by 2.55 to convert from a cord to cubic meters of solid material. AD = air-dry.

[c] Percentage nitrogen also provided for quaking aspen.

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## Metric Equivalents

| When you know: | Multiply by: | To find: |
|---|---|---|
| British thermal units (Btu) | 0.252 | Kilocalories |
| British thermal units (Btu) | 1054.35 | Joule |
| British thermal units per pound (Btu/lb) | .002326 | Megajoules per kilogram |
| British thermal units per air-dry cord (Btu/AD cord) | 413.47 | Megajoules per AD cubic meter |
| Feet (ft) | .305 | Meters |
| Cubic feet ($ft^3$) | .0283 | Cubic meters |
| Pounds (lb) | .454 | Kilograms |
| Pounds per cubic foot ($lb/ft^3$) | 16.02 | Kilograms per cubic meter |
| Degrees Fahrenheit (°F) | .56(°F - 32) | Degrees Celsius |

[4] The second paragraph gives the original Acknowledgments; thus, some of the affiliations and employments have changed since 1987.

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# Appendix

## Explanation of Conversions Made in the Updated Report and Editors Comment

In the original publication, the term total weight (TW) was used to define the initial (fresh or green) weight of the sample before drying, and all moisture contents were reported by using an oven-dry (OD) basis. Given that energy-related conversions use green-weight moisture contents, this revised publication provides OD moisture contents converted to green basis (assumed to be 50-percent moisture content TW) in the tables. It was determined that having ash content reported as a percentage of green weight as well as a percentage of OD weight would also be helpful.

Wood is hygroscopic, meaning it has the ability to exchange (absorb or desorb) moisture with its surrounding environment. Once the wood has been converted from the living tree to product form (e.g., firewood, chips, lumber, or veneer), the inorganic components that create ash are fixed and, for most analytical purposes, constant for a given piece of material. The weight of the material per unit of volume, however, will fluctuate as moisture is exchanged with the atmosphere.

Determination of moisture content (MC) of wood and bark is a relatively simple matter of taking a sample, weighing it, drying it in an oven at a temperature of 103 ± 2 °C (217 ± 4 °F), and periodically reweighing the material until a stable weight is obtained. At the point the material is referred to as “bone” or “oven” dry, all of the free water between cells and bound water from the interior of the cells has been removed. This condition is also referred to as zero percent MC. There is still water that is bound to the chemical structure of the wood, but removal of this material requires temperatures above the boiling point of water; as the material is removed, the chemical structure of the wood material is altered. This process is referred to as destructive distillation and is often accompanied by a charring of the material.

Moisture meters can also be used to measure the moisture content of wood. These meters, however, are based on resistance, dielectric constant, or power loss factor. The point in drying where resistance starts to increase is referred to as the fiber saturation point (fsp). In changes in moisture content above the fsp, there is no shrinkage or expansion in the physical dimensions of a piece of solid wood, lumber, veneer, or bark. As changes take place below the fsp, the physical dimensions of the material will change. These changes in dimension, however, are relatively minor and inconsequential in relation to the changes in mass, unless the material is being used for finish in a heated or air conditioned building. In such situations, material should be conditioned so that the material has an MC very near the equilibrium conditions where it will be put into service. Note that meters do not accurately measure the MC of wood material that is saturated with water. The meter indicates that the wood is saturated but does not really provide a valid estimate of how much water it contains.

Given the hygroscopic nature of wood, once it is removed from the stump, the wood is always changing moisture content to reach equilibrium with the surrounding atmosphere. In the fresh-cut condition, the weight of water can be greater than the weight of the wood substance in a piece of wood, but the instant the material is cut from the stump, the process of moving to equilibrium conditions begins. The *Wood Handbook* (USDA FS 1999) published tables showing average equilibrium MC at various locations in the United States. Users of these tables should be aware that there is a difference between how wood scientists interested in forest products and engineers concerned with energy relationships calculate MC of wood material.

Owing to the ever-changing moisture content of the material to equilibrium conditions, wood technologists calculate moisture content as a percentage of the OD condition. This condition is absolute and a piece of wood can repeatedly be returned to it. Engineers concerned with energy values use the original, initial sample (total or green weight) as the basis for determining MC. In all manipulations of MC, users are reminded that the OD condition may be repeatedly obtained. The green condition is a function of many factors and is often referenced to such terms as “the living tree,” “fresh cut,” or “undried.” In the living tree, there is usually a major difference between wood from the sapwood and heartwood portions of the tree. In the commerce of the forest products industry, the term “fresh cut” implies that the material has recently been harvested and with minimal delays transported to a mill where the amount harvested and delivered is based on weight at the stated condition. In cold climates, “fresh weight” may include ice and snow, and in any climate, it may include contamination in the form of dirt, mud, and rocks. Given an awareness of all of these problems, the editors have used an MC of 50 percent (TW or green basis) as the best estimate for the original condition soon after harvest. Depending on the time of year, the MC of chips, sawdust, and bark, singularly or in combination, may be above or below the 50 percent green basis MC, depending on exposure to rain or snow. Therefore, a piece of wood that has an MC of 100 percent (OD basis) is considered to have an MC of 50 percent (TW or green basis). The formulas for calculating MC by the two methods are shown in table 1 of the text (equations (2) and (3)). Once calculated, an MC value from one basis can be converted to the alternative basis using equations (4) and (5) in table 1.

In a similar manner, these equations can be manipulated so the material weights at any stated MC can be adjusted to some other desired MC. Frequently, engineers working on the design of combustion systems want to convert OD weight basis values to TW or green values. To convert the weight of material from one MC basis to another, view the conversion as a two-stage process. First, if the material is not oven dry, convert it to the oven-dry condition.

If the starting MC is a percentage of OD weight, then the formula is:

$$\text{OD weight} = \text{weight at the specified MC} / (1 + \text{percentage MC at OD basis} / 100) \quad (7)$$

If the starting MC is a percentage of green weight, then the formula is:

$$\text{OD weight} = \text{weight at the specified MC} \times (1 - \text{percentage MC at wet weight} / 100) \quad (8)$$

For example, assume you have 100 lb of material at an MC of 25 percent (OD basis). Equation (7) can then be used to calculate an OD weight of 80 lb (100 / (1 + 25/100)). Likewise, for 100 lb of material at 20 percent MC (wet or green basis), equation (8) can be used to calculate an OD weight of 80 lb (100 x (1 - 20/ 100)). Once the OD weight is calculated, equation (8) can be used to calculate the weight of the sample at any other moisture content.

Ash, a residual material left after burning, results from inorganic compounds that remain after high-temperature combustion takes place. Such chemicals include calcium, potassium, magnesium, manganese, and silicon. Ash content is usually reported as a percentage of the oven-dry weight of wood. The formula for converting from dry basis to green basis is almost exactly the same as that for moisture content. Equations (7) and (8) can be used to convert ash content at a specified MC to a second MC. Note that the weight of the inorganic material is constant, regardless of the MC. Thus, as MC changes, it is the gain or loss of water and not the basic chemical composition of the wood that changes. If the ash content of an oven-dry sample of 10 lb of wood is 1.8 percent (0.018), then the ash resulting from burning will be 0.18 lb (10 lb x 0.018). If the ash content is desired in relation to some other MC, use equations (7) and (8) to calculate the weight of the 10-lb sample at the second MC. If ash content is desired in relation to the green condition, assumed as 50 percent MC (TW or green basis) or 100 percent MC (OD basis), then the green weight of the sample increases to 20 lb (increase in weight is all water) and the new percentage is 0.18 lb divided by 20 lb (0.009 or 0.9 percent ash).

Conversions made in this updated report were based on the above information. In tables 3, 4, 9, and 10, we reported MC in both the original OD basis and the converted TW or green basis, assumed as an MC of 50 percent TW or 100 percent dry basis. The conversions were made by using equation (5) in table 1. In the calculated green basis value, we carried the same number of decimal places as the original report. All other data are reported as per the original publication.

Tables 5 and 11 show the heating values and ash contents using units reported in the original publication. Tables 6 and 12 show the heating values converted to the metric or International System of units. Values originally reported in metric units were not changed. Ash contents were converted from OD basis to wet basis based on the discussion above.

Likewise, tables 7 and 13 show the higher heating values and ash contents using the units reported in the original publication. Tables 8 and 14 show the higher heating values converted to SI units and ash content based on wet weight. To make the conversion for the higher heating value by volume, we assumed that a cord is a pile of wood 4 ft by 4 ft by 8 ft that includes wood, bark, and air. Thus, one cord contains 128 $ft^3$ of stacked roundwood, which is about 90 $ft^3$ of solid material. If a cord is converted to stacked meters, then this converts to about 2.55 $m^3$ of solid material. Thus, the conversion from British thermal units per air-dried cord to megajoules per cubic meter was made by multiplying the original value by 1,054.35 and dividing by 2.55 (or simply multiplying by 413.47).

The word “clean” can be used to describe residual products (chips, sawdust, bark, and hog fuel) that have been moved (blown or conveyed) from the production process to vans or railcars for transport or a clean asphalt or cement pad for temporary storage. If the material is in temporary storage, dedicated equipment (e.g., dozers, loaders) that is kept completely free of mud, rocks, and dirt is used to handle the material and prevent contamination. Energy systems may have less stringent material requirements than the pulp and paper industry, but most of the basic rules of the pulp and paper industry apply. It is observed that many firms interested in converting to renewable energy systems have initially focused on the burning technology, only to discover during the startup operation that most of the problems are associated with fuel characteristics and handling. The major problems with burning biomass material are contamination and moisture not associated with the basic MC and ash content of the material, but resulting from poor handling, storage, and delivery to the burning site.

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