



# Biomass Energy Data Book

## Edition 2



U.S. Department of Energy  
**Energy Efficiency and Renewable Energy**

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable





## USEFUL WEB SITES

### GOVERNMENT LINKS

U.S. DEPARTMENT OF AGRICULTURE	<a href="http://www.usda.gov">www.usda.gov</a>
Agricultural Research Service	<a href="http://www.ars.usda.gov">www.ars.usda.gov</a>
Forest Service	<a href="http://www.fs.fed.us">www.fs.fed.us</a>
National Agricultural Library	<a href="http://www.nal.usda.gov">www.nal.usda.gov</a>
National Agricultural Statistics Service	<a href="http://www.nass.usda.gov">www.nass.usda.gov</a>
U.S. DEPARTMENT OF ENERGY	<a href="http://www.energy.gov">www.energy.gov</a>
Energy Efficiency and Renewable Energy	<a href="http://www.eere.energy.gov">www.eere.energy.gov</a>
Biomass Program	<a href="http://www.eere.energy.gov/biomass">www.eere.energy.gov/biomass</a>
Alternative Fuels Data Center	<a href="http://www.eere.energy.gov/afdc">www.eere.energy.gov/afdc</a>
Clean Cities	<a href="http://www.eere.energy.gov/cleancities">www.eere.energy.gov/cleancities</a>
Fuel Economy	<a href="http://www.fueleconomy.gov">www.fueleconomy.gov</a>
<b>Biomass Energy Data Book</b>	<a href="http://cta.ornl.gov/bedb">cta.ornl.gov/bedb</a>
<i>Buildings Energy Data Book</i>	<a href="http://www.btscoredatabook.net">www.btscoredatabook.net</a>
<i>Power Technologies Data Book</i>	<a href="http://www.nrel.gov/analysis/power_databook">www.nrel.gov/analysis/power_databook</a>
<i>Transportation Energy Data Book</i>	<a href="http://cta.ornl.gov/data">cta.ornl.gov/data</a>
Energy Information Administration	<a href="http://www.eia.doe.gov">www.eia.doe.gov</a>
IDAHO NATIONAL LABORATORY	<a href="http://www.inl.gov">www.inl.gov</a>
NATIONAL RENEWABLE ENERGY LABORATORY	<a href="http://www.nrel.gov">www.nrel.gov</a>
OAK RIDGE NATIONAL LABORATORY	<a href="http://www.ornl.gov">www.ornl.gov</a>
Center for Transportation Analysis	<a href="http://cta.ornl.gov">cta.ornl.gov</a>
PACIFIC NORTHWEST NATIONAL LABORATORY	<a href="http://www.pnl.gov">www.pnl.gov</a>
USA.GOV	<a href="http://www.usa.gov">www.usa.gov</a>
FEDERAL GOVERNMENT – FEDSTATS	<a href="http://www.fedstats.gov">www.fedstats.gov</a>
U.S. BUREAU OF LABOR STATISTICS	<a href="http://www.bls.gov">www.bls.gov</a>
U.S. CENSUS BUREAU	<a href="http://www.census.gov">www.census.gov</a>
U.S. DEPARTMENT OF COMMERCE	<a href="http://www.commerce.gov">www.commerce.gov</a>
Bureau of Economic Analysis	<a href="http://www.bea.gov">www.bea.gov</a>
U.S. ENVIRONMENTAL PROTECTION AGENCY	<a href="http://www.epa.gov">www.epa.gov</a>

### NON GOVERNMENT LINKS

American Corn Growers Association	<a href="http://www.acga.org">www.acga.org</a>
American Soybean Association	<a href="http://www.soygrowers.com">www.soygrowers.com</a>
National Biodiesel Board	<a href="http://www.biodiesel.org">www.biodiesel.org</a>
National Oilseed Processors Association	<a href="http://www.nopa.org">www.nopa.org</a>
National Ethanol Vehicle Coalition	<a href="http://www.e85fuel.com">www.e85fuel.com</a>
Pellet Fuels Institute	<a href="http://pelletheat.org">pelletheat.org</a>
Renewable Fuels Association	<a href="http://www.ethanolrfa.org">www.ethanolrfa.org</a>

**BIOMASS ENERGY DATA BOOK:  
EDITION 2**

**Lynn Wright**

Consultant  
Oak Ridge, Tennessee

**Bob Boundy**

Roltek  
Clinton, Tennessee

**Philip C. Badger**

General Bioenergy, Inc.  
Florence, Alabama

**Bob Perlack**

**Stacy Davis**

Oak Ridge National Laboratory  
Oak Ridge, Tennessee

December 2009

Prepared for the  
Office of the Biomass Program  
Energy Efficiency and Renewable Energy  
U.S. Department of Energy

Prepared by the  
Oak Ridge National Laboratory  
Oak Ridge, Tennessee 37831-6073  
managed by  
UT-BATTELLE, LLC  
for the  
U.S. DEPARTMENT OF ENERGY  
under Contract No. DE-AC05-00OR22725

## **APPENDIX A**

### **CONVERSIONS**



**Table A.1**  
**Lower and Higher Heating Values of Gas, Liquid and Solid Fuels**

Fuels	Lower Heating Value (LHV) [1]			Higher Heating Value (HHV) [1]			Density
	Btu/ft <sup>3</sup> [2]	Btu/lb [3]	MJ/kg [4]	Btu/ft <sup>3</sup> [2]	Btu/lb [3]	MJ/kg [4]	grams/ft <sup>3</sup>
<b>Gaseous Fuels @ 32 F and 1 atm</b>							
Natural gas	983	20,267	47.141	1089	22,453	52.225	22.0
Hydrogen	290	51,682	120.21	343	61,127	142.18	2.55
Still gas (in refineries)	1458	20,163	46.898	1,584	21,905	50.951	32.8
<b>Liquid Fuels</b>							
Crude oil	129,670	18,352	42.686	138,350	19,580	45.543	3,205
Conventional gasoline	116,090	18,679	43.448	124,340	20,007	46.536	2,819
Reformulated or low-sulfur gasoline	113,602	18,211	42.358	121,848	19,533	45.433	2,830
CA reformulated gasoline	113,927	18,272	42.500	122,174	19,595	45.577	2,828
U.S. conventional diesel	128,450	18,397	42.791	137,380	19,676	45.766	3,167
Low-sulfur diesel	129,488	18,320	42.612	138,490	19,594	45.575	3,206
Petroleum naphtha	116,920	19,320	44.938	125,080	20,669	48.075	2,745
NG-based FT naphtha	111,520	19,081	44.383	119,740	20,488	47.654	2,651
Residual oil	140,353	16,968	39.466	150,110	18,147	42.210	3,752
Methanol	57,250	8,639	20.094	65,200	9,838	22.884	3,006
Ethanol	76,330	11,587	26.952	84,530	12,832	29.847	2,988
Butanol	99,837	14,775	34.366	108,458	16,051	37.334	3,065
Acetone	83,127	12,721	29.589	89,511	13,698	31.862	2,964
E-Diesel Additives	116,090	18,679	43.448	124,340	20,007	46.536	2,819
Liquefied petroleum gas (LPG)	84,950	20,038	46.607	91,410	21,561	50.152	1,923
Liquefied natural gas (LNG)	74,720	20,908	48.632	84,820	23,734	55.206	1,621
Dimethyl ether (DME)	68,930	12,417	28.882	75,610	13,620	31.681	2,518
Dimethoxy methane (DMM)	72,200	10,061	23.402	79,197	11,036	25.670	3,255
Methyl ester (biodiesel, BD)	119,550	16,134	37.528	127,960	17,269	40.168	3,361
Fischer-Tropsch diesel (FTD)	123,670	18,593	43.247	130,030	19,549	45.471	3,017
Renewable Diesel I (SuperCetane)	117,059	18,729	43.563	125,294	20,047	46.628	2,835
Renewable Diesel II (UOP-HDO)	122,887	18,908	43.979	130,817	20,128	46.817	2,948
Renewable Gasoline	115,983	18,590	43.239	124,230	19,911	46.314	2,830
Liquid Hydrogen	30,500	51,621	120.07	36,020	60,964	141.80	268
Methyl tertiary butyl ether (MTBE)	93,540	15,094	35.108	101,130	16,319	37.957	2,811
Ethyl tertiary butyl ether (ETBE)	96,720	15,613	36.315	104,530	16,873	39.247	2,810
Tertiary amyl methyl ether (TAME)	100,480	15,646	36.392	108,570	16,906	39.322	2,913
Butane	94,970	19,466	45.277	103,220	21,157	49.210	2,213
Isobutane	90,060	19,287	44.862	98,560	21,108	49.096	2,118
Isobutylene	95,720	19,271	44.824	103,010	20,739	48.238	2,253
Propane	84,250	19,904	46.296	91,420	21,597	50.235	1,920
<b>Solid Fuels</b>							
Coal (wet basis) [6]	19,546,300	9,773	22.732	20,608,570	10,304	23.968	
Bituminous coal (wet basis) [7]	22,460,600	11,230	26.122	23,445,900	11,723	27.267	
Coking coal (wet basis)	24,600,497	12,300	28.610	25,679,670	12,840	29.865	
Farmed trees (dry basis)	16,811,000	8,406	19.551	17,703,170	8,852	20.589	
Herbaceous biomass (dry basis)	14,797,555	7,399	17.209	15,582,870	7,791	18.123	
Corn stover (dry basis)	14,075,990	7,038	16.370	14,974,460	7,487	17.415	
Forest residue (dry basis)	13,243,490	6,622	15.402	14,164,160	7,082	16.473	
Sugar cane bagasse	12,947,318	6,474	15.058	14,062,678	7,031	16.355	
Petroleum coke	25,370,000	12,685	29.505	26,920,000	13,460	31.308	

**Source:**

GREET Transportation Fuel Cycle Analysis Model, GREET 1.8b, developed by Argonne National Laboratory, Argonne, IL, released May 8, 2008.

<http://www.transportation.anl.gov/software/GREET/index.html>

**Notes:**

[1] The **lower heating value** (also known as net calorific value) of a fuel is defined as the amount of heat released by combusting a specified quantity (initially at 25°C) and returning the temperature of the combustion products to 150°C, which assumes the latent heat of vaporization of water in the reaction products is not recovered. The LHV are the useful calorific values in boiler combustion plants and are frequently used in Europe.

The **higher heating value** (also known as gross calorific value or gross energy) of a fuel is defined as the amount of heat released by a specified quantity (initially at 25°C) once it is combusted and the products have returned to a temperature of 25°C, which takes into account the latent heat of vaporization of water in the combustion products. The HHV are derived only under laboratory conditions, and are frequently used in the US for solid fuels.

**Table A.1 (Continued)**  
**Lower and Higher Heating Values of Gas, Liquid and Solid Fuels**

- [2] Btu = British thermal unit.
- [3] The heating values for gaseous fuels in units of Btu/lb are calculated based on the heating values in units of Btu/ft<sup>3</sup> and the corresponding fuel density values. The heating values for liquid fuels in units of Btu/lb are calculated based on heating values in units of Btu/gal and the corresponding fuel density values.
- [4] The heating values in units of MJ/kg, are converted from the heating values in units of Btu/lb.
- [5] For solid fuels, the heating values in units of Btu/lb are converted from the heating values in units of Btu/ton.
- [6] Coal characteristics assumed by GREET for electric power production.
- [7] Coal characteristics assumed by GREET for hydrogen and Fischer-Tropsch diesel production.

**Table A.2**  
**Heat Content Ranges for Various Biomass Fuels (dry weight basis<sup>a</sup>) with English and Metric Units**

Fuel type & source	English			Metric <sup>b</sup>			
	Btu/lb <sup>c</sup>	Higher Heating Value		Higher Heating Value		Lower Heating Value	
		Btu/lb	MBtu/ton	kJ/kg	MJ/kg	kJ/kg	MJ/kg
<b>Agricultural Residues</b>							
Corn stalks/stover (1,2,6)	7,487	7,587 - 7,967	15.2 - 15.9	17,636 - 18,519	17.6 - 18.5	16,849 - 17,690	16.8 - 18.1
Sugarcane bagasse (1,2,6)	7,031	7,450 - 8,349	14.9 - 16.7	17,317 - 19,407	17.3 - 19.4	17,713 - 17,860	17.7 - 17.9
Wheat straw (1,2,6)		6,964 - 8,148	13.9 - 16.3	16,188 - 18,940	16.1 - 18.9	15,082 - 17,659	15.1 - 17.7
hulls, shells, prunings (2,3)		6,811 - 8,838	13.6 - 17.7	15,831 - 20,543	15.8 - 20.5		
fruit pits (2-3)		8,950 - 10,000	17.9 - 20.0				
<b>Herbaceous Crops</b>							
Miscanthus (6)	7,791			18,100 - 19,580	18.1 - 19.6	17,818 - 18,097	17.8 - 18.1
switchgrass (1,3,6)		7,754 - 8,233	15.5 - 16.5	18,024 - 19,137	18.0 - 19.1	16,767 - 17,294	16.8 - 18.6
Other grasses (6)				18,185 - 18,570	18.2 - 18.6	16,909 - 17,348	16.9 - 17.3
Bamboo (6)				19,000 - 19,750	19.0 - 19.8		
<b>Woody Crops</b>							
Black locust (1,6)	8,852	8,409 - 8,582	16.8 - 17.2	19,546 - 19,948	19.5 - 19.9	18,464	18.5
eucalyptus (1,2,6)		8,174 - 8,432	16.3 - 16.9	19,000 - 19,599	19.0 - 19.6	17,963	18.0
hybrid poplar (1,3,6)		8,183 - 8,491	16.4 - 17.0	19,022 - 19,737	19.0 - 19.7	17,700	17.7
willow (2,3,6)		7,983 - 8,497	16.0 - 17.0	18,556 - 19,750	18.6 - 19.7	16,734 - 18,419	16.7 - 18.4
<b>Forest Residues</b>							
Hardwood wood (2,6)	7,082	8,017 - 8,920	16.0 - 17.5	18,635 - 20,734	18.6 - 20.7		
Softwood wood (1,2,3,4,5,6)		8,000 - 9,120	16.0 - 18.24	18,595 - 21,119	18.6 - 21.1	17,514 - 20,768	17.5 - 20.8
<b>Urban Residues</b>							
MSW (2,6)		5,644 - 8,542	11.2 - 17.0	13,119 - 19,855	13.1 - 19.9	11,990 - 18,561	12.0 - 18.6
RDF (2,6)		6,683 - 8,563	13.4 - 17.1	15,535 - 19,904	15.5 - 19.9	14,274 - 18,609	14.3 - 18.6
newspaper (2,6)		8,477 - 9,550	17 - 19.1	19,704 - 22,199	19.7 - 22.2	18,389 - 20,702	18.4 - 20.7
corrugated paper (2,6)		7,428 - 7,939	14.9 - 15.9	17,265 - 18,453	17.3 - 18.5	17,012	
waxed cartons (2)		11,727 - 11,736	23.5 - 23.5	27,258 - 27,280	27.3	25,261	

**Sources:**

- [1] [http://www1.eere.energy.gov/biomass/feedstock\\_databases.html](http://www1.eere.energy.gov/biomass/feedstock_databases.html)
- [2] Jenkins, B., *Properties of Biomass*, Appendix to Biomass Energy Fundamentals, EPRI Report TR-102107, January 1993.
- [3] Jenkins, B., L. Baxter, T. Miles, Jr. and T. Miles T., *Combustion Properties of Biomass, Fuel Processing Technology* 54, pg. 17-46, 1998.
- [4] Tillman, David, *Wood as an Energy Resource*, Academic Press, New York, 1978.
- [5] Bushnell, D., *Biomass Fuel Characterization: Testing and Evaluating the Combustion Characteristics of Selected Biomass Fuels*, BPA report, 1989.
- [6] <http://www.ecn.nl/phyllis>

<sup>a</sup> This table attempts to capture the variation in reported heat content values (on a dry weight basis) in the United States and European literature based on values in the Phyllis database, the U.S. DOE/EERE feedstock database, and selected literature sources. Table A.3 of this document provides information on heat contents of materials "as received" with varying moisture contents.

<sup>b</sup> Metric values include both HHV and LHV since Europeans normally report the LHV (or net calorific values) of biomass fuels.

<sup>c</sup> HHV assumed by GREET model given in Table A.1 of this document



The heating value of any fuel is the heat release per unit mass when the fuel initially at 25°C (77°F) reacts completely with oxygen, and the products are returned to 25°C (77°F). The heating value is reported as the higher heating value (HHV) when the water is condensed or as the lower heating value (LHV) when the water is not condensed. The LHV is obtained from the HHV by subtracting the heat of vaporization of water in the products. Thus:  $LHV = HHV - ((mH_2O/m_{fuel}) \cdot h_{fg})$  where  $m$  = mass and  $h_{fg}$  is the latent heat of vaporization of water at 25°C (77°F) which equals 2,440 kJ/kg water (1,050 Btu/lbm). The water includes moisture in the fuel as well as water formed from hydrogen in the fuel.

The HHV and LHV provided in Tables 1 and 2 of the Biomass Energy Data Book, Appendix A assume that the fuels contain 0% water. Since recently harvested wood fuels usually contain 30 to 55% water it is useful to understand the effect of moisture content on the heating value of wood fuels. The table below shows the effect of percent moisture content (MC) on the higher heating value as-fired (HHV-AF) of a wood sample starting at 8,500 Btu/lb (oven-dry).

**Table A.3**  
**The Effect of Fuel Moisture on Wood Heat Content<sup>a</sup>**

Moisture Content (MC) wet basis (%)	0	15	20	25	30	35	40	45	50	55	60
Higher Heating Value as fired (HHV-AF) Btus/lb	8,500	7,275	6,800	6,375	5,950	5,525	5,100	4,575	4,250	3,825	3,400

**Sources:**

- [1] Borman, G.L. and K.W. Ragland, *Combustion Engineering*. McGraw-Hill, 613 pp, 1998.
- [2] Maker, T.M., *Wood-Chip Heating Systems: A Guide for Institutional and Commercial Biomass Installations*, 2004. (Revised 2004 by Biomass Energy Resource Center).
- [3] American Pulpwood Association, Southern Division Office, *The Forester's Wood Energy Handbook*, 1980.

**Notes:** Moisture contents (MC) wet and dry weight basis are calculated as follows:

MC (dry basis) = 100 (wet weight-dry weight)/dry weight;

MC (wet basis) = 100 (wet weight – dry weight)/wet weight;

To convert MC wet basis to MC dry basis:  $MC(dry) = 100 \times MC(wet) / 100 - MC(wet)$ ;

To convert MC dry basis to MC wet basis:  $MC(wet) = 100 \times MC(dry) / 100 + MC(dry)$ .

Some sources report heat contents of fuels “as-delivered” rather than at 0% moisture for practical reasons. Because most wood fuels have bone dry (oven-dry) heat contents in the range of 7,600 to 9,600 Btu/lb (15,200,000 to 19,200,000 Btu/ton or 18 to 22 GJ/Mg), lower values will always mean that some moisture is included in the delivered fuel. Grass fuels are usually delivered at < 20% MC.

<sup>a</sup> If the oven-dry HHV (Btu /lb )is known (e.g. 8,500) then the HHV-AF can be calculated as follows: oven-dry HHV x (1-MC wet basis/100).

**Table A.4**  
**Forestry Volume Unit to Biomass Weight Considerations**

Biomass is frequently estimated from forestry inventory merchantable volume data, particularly for purposes of comparing regional and national estimates of aboveground biomass and carbon levels. Making such estimations can be done several ways but always involves the use of either conversion factors or biomass expansion factors (or both combined) as described by figure 1 below. Figure 2 clarifies the issue further by defining what is included in each category of volume or biomass units.

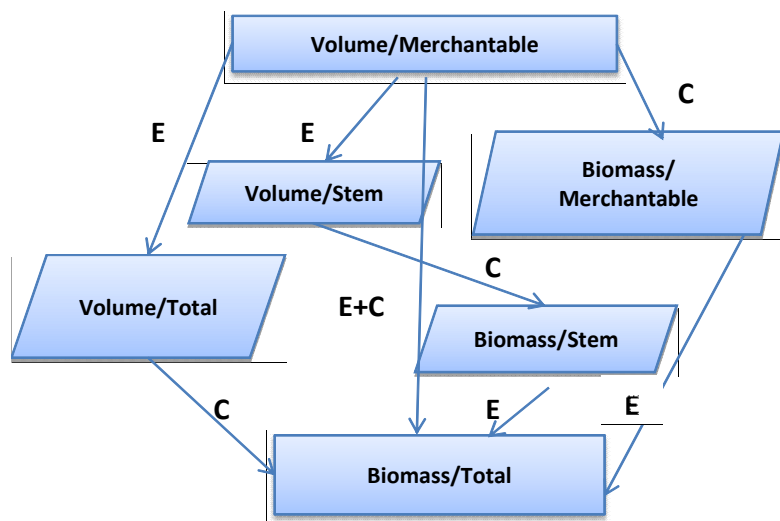
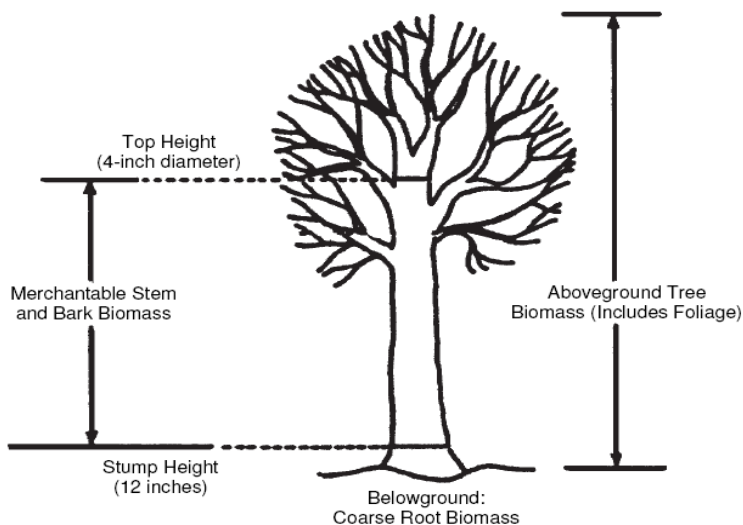


Figure 1 Source: Somogyi Z. et al. Indirect methods of large-scale biomass estimation. Eur J Forest Res (2006) DOI 10.1007/s10342-006-0125-7



Unfortunately definitions used in figure 1 are not standardized worldwide, but figure 2 below demonstrates definitions used in the United States for forest inventory data. The merchantable volume provided by forest inventory reports commonly refers only to the underbark volume or biomass of the main stem above the stump up to a 4 inch (10 cm) top. Merchantable stem volume can be converted (symbolized by C in Fig. 1) to merchantable biomass. Both merchantable volume and biomass must be expanded (symbolized by E in Fig. 1) to include the bark for stem volume or biomass. Further expansion is needed to obtain the total volume or biomass which includes stem, bark, stump, branches and foliage, especially if evergreen trees are being measured. When estimating biomass available for bioenergy, the foliage is not included and the stump may or may not be appropriate to include depending on whether harvest occurs at ground level or higher. Both conversion and expansion factors can be used together to translate directly between merchantable volumes per unit area and total biomass per unit area (see table A5, Appendix A).

Figure 2 Source: Jenkins, JC, Chojnacky DC, Heath LS, Birdsey RA. Comprehensive Database of Diameter-based Biomass Regressions for North American Tree Species. United States Department of Agriculture, Forest Service General Technical Report NE-319, pp 1-45 (2004)

**Table A.5**  
**Estimation of Biomass Weights from Forestry Volume Data**

**Simple volume to weight conversion**

An equation for estimation of merchantable biomass from merchantable volume assuming the specific gravity and moisture content are known and the specific gravity basis corresponds to the moisture content of the volume involved.

$$\text{Weight} = (\text{volume}) * (\text{specific gravity}) * (\text{density of H}_2\text{O}) * (1 + \text{MC}^{\text{od}}/100)$$

where volume is expressed in cubic feet or cubic meters,

where the density of water is 62.4 lb/ft<sup>3</sup> or 1000 kg/m<sup>3</sup>,

where MC<sup>od</sup> equals oven dry moisture content.

for example the weight of fiber in an oven dry log of 44 ft<sup>3</sup> with a specific gravity of 0.40 =  
40 ft<sup>3</sup>\*0.40 \* 62.4 lb ft<sup>3</sup> \* (1+0/100) equals 1,098 lb or 0.549 dry ton

**Source:** Briggs D. 1994. Forest Products Measurements and Conversion Factors, Chapter 1. College of Forest Resources University of Washington.

[http://www.ruraltech.org/projects/conversions/briggs\\_conversions/briggs\\_book.asp](http://www.ruraltech.org/projects/conversions/briggs_conversions/briggs_book.asp)

**Specific gravity (SG)** is a critical element of the volume to biomass estimation equation. The SG content should correspond to the moisture content of the volume involved. SG varies considerably from species to species, differs for wood and bark, and is closely related to the moisture content as explained in graphs and tables in Briggs (1994). The wood specific gravity of species can be found in several references though the moisture content basis is not generally given. Briggs (1994) suggests that a moisture content of 12% is the standard upon which many wood properties measurements are based.

**Biomass expansion factors for estimating total aboveground biomass Mg ha<sup>-1</sup> from growing stock volume data (m<sup>3</sup> ha<sup>-1</sup>)**

Methods for estimating total aboveground dry biomass per unit area from growing stock volume data in the USDA ForestService FIA database were described by Schroeder et. al (1997).

The growing stock volume was by definition limited to trees > than or equal to 12.7 cm diameter. It is highly recommended that the paper be studied for details of how the biomass expansion factors (BEF) for oak-hickory and beech-birch were developed.

The BEFs for the two forest types were combined and reported as:

$$\text{BEF} = \text{EXP} (1.912 - 0.344 * \ln \text{GSV}) \quad \text{GSV} = \text{growing stock volume m}^3 \text{ ha}^{-1}$$

R<sup>2</sup> = 0.85, n = 208 forest units, std. error of estimate = 0.109.

The result is curvilinear with BEF values ranging from 3.5 to 1.5 for stands with very low growing stock volume and approaching the value of 1 at high growing stock volumes.

Minimum BEFs for the forest types evaluated are estimated to be about 0.61 to 0.75.

**Source:** Schroeder P, Brown S, Mo J, Birdsey R, Cieszewski C. 1997. Biomass estimation for temperate broadleaf forests of the US using forest inventory data. Forest Science 43, 424-434.

**Table A.6**  
**Forestry Volume Unit to Biomass Weight Examples**  
**(Selected Examples from the North Central Region)**

Species Group	Specific gravity wood <sup>a</sup>	Specific gravity bark <sup>a</sup>	Green MC wood & bark (%)	Green weight wood & bark lb/ft <sup>3</sup>	Dry weight wood & bark lb/ft <sup>3</sup>	Green weight of solid cord <sup>b</sup> (lbs)	Green weight of solid cord <sup>b</sup> (tons) <sup>c</sup>	Air-dry tons per solid cord <sup>b</sup> 15% MC <sup>c</sup>	Oven-dry tons per solid cord 0% MC <sup>c</sup>
<b>Softwood</b>									
Southern Pine	0.47	0.32	50	64	32	5,056	2.5	1.5	1.3
Jack Pine	0.40	0.34	47	54	29	4,266	2.1	1.3	1.1
Red Pine	0.41	0.24	47	54	29	4,266	2.1	1.3	1.1
White Pine	0.37	0.49	47	53	28	4,187	2.1	1.3	1.1
<b>Hardwood</b>									
Red Oak	0.56	0.65	44	73	41	5,767	2.9	1.9	1.6
Beech	0.56	0.56	41	64	38	5,056	2.5	1.7	1.5
Sycamore	0.46	0.45	55	62	28	4,898	2.4	1.3	1.1
Cottonwood	0.37	0.43	55	59	27	4,661	2.3	1.2	1.0
Willow	0.34	0.43	55	56	25	4,424	2.2	1.1	1.0

**Source:**

Smith, B., *Factors and Equations to Estimate Forest Biomass in the North Central Region*, 1985, U.S. Department of Agriculture, Forest Service, North Central Experimental Station Research Paper NC-268, 1985. (This paper quotes many original literature sources for the equations and estimates.)

**Note:** A caution: In extensive online research for reference sources that could provide guidance on estimating biomass per unit area from volume data (e.g., m<sup>3</sup>, ft<sup>3</sup> or board ft), several sources of conversion factors and "rules of thumb" were found that provided insufficient information to discern whether the reference was applicable to estimation of biomass availability. For instance moisture contents were not associated with either the volume or the weight information provided. These "rule of thumb" guides can be useful when fully understood by the user, but they can be easily misinterpreted by someone not understanding the guide's intent. For this reason, most simple "rules of thumb guides" are not useful for converting forest volume data to biomass estimates.

<sup>a</sup> The SG numbers are based on weight oven-dry and volume when green (Smith, 1985; table 1) of wood and bark respectively. Wood and bark are combined for other columns (Smith, 1985, table 2).

<sup>b</sup> A standard solid cord for the north central region was determined by Smith, 1985 to be 79 ft<sup>3</sup> rather than the national average of 80 ft<sup>3</sup> as used in table A9 in appendix A.

<sup>c</sup> The green weight values in lbs provided by the Smith (1985) paper were converted to green tons, air-dry tons and oven-dry tons for convenience of the user.

**Table A.7**  
**Stand Level Biomass Estimation**

---

*Biomass estimation at the individual field or stand level is relatively straight forward, especially if being done for plantation grown trees that are relatively uniform in size and other characteristics. The procedure involves first developing a biomass equation that predicts individual tree biomass as a function of diameter at breast height (dbh), or of dbh plus height. Secondly, the equation parameters (dbh and height) need to be measured on a sufficiently large sample size to minimize variation around the mean values, and thirdly, the mean individual tree weight results are scaled to the area of interest based on percent survival or density information (trees per acre or hectare). Regression estimates are developed by directly sampling and weighing enough trees to cover the range of sizes being included in the estimation. They often take the form of:*

*In  $Y$  (weight in kg) = -factor 1 + factor 2 x  $\ln X$  (where  $X$  is dbh or  $dbh^2 + \text{height}/100$ ) Regression equations can be found for many species in a wide range of literature. Examples for trees common to the Pacific Northwest are provided in reference 1 below. The equations will differ depending on whether foliage or live branches are included, so care must be taken in interpreting the biomass data. For plantation trees grown on cropland or marginal cropland it is usually assumed that tops and branches are included in the equations but that foliage is not. For trees harvested from forests on lower quality land, it is usually recommended that tops and branches should not be removed (see reference 2 below) in order to maintain nutrient status and reduce erosion potential, thus biomass equations should assume regressions based on the stem weight only.*

---

**Sources:**

- [1] Briggs, D., *Forest Products Measurements and Conversion Factors*. College of Forest Resources University of Washington. Available as of 9/29/2008 at:  
[http://www.ruraltech.org/projects/conversions/briggs\\_conversions/briggs\\_book.asp](http://www.ruraltech.org/projects/conversions/briggs_conversions/briggs_book.asp)
- [2] Pennsylvania Department of Conservation and Natural Resources, *Guidance on Harvesting Woody Biomass for Energy in Pennsylvania*. September 2007. Available as of 9-29-08 at:  
[http://www.dcnr.state.pa.us/PA\\_Biomass\\_guidance\\_final.pdf](http://www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf)



**Table A.8**  
**Number of Trees per Acre and per Hectare by Various Tree Spacing Combinations**

Spacing (feet) =	Trees per Acre =	Spacing (meters) =	Trees per Hectare <sup>a</sup>	Spacing (meters)=	Trees per Hectare	Spacing (ft and in ) =	Trees per Acre <sup>b</sup>
1 x 1	43,560	0.3 x 0.3	107,637	0.1 x 0.1	1,000,000	4" x 4 "	405,000
2 x 2	10,890	0.6 x 0.6	26,909	0.23 x 0.23	189,035	9" x 9 "	76,559
2 x 4	5,445	0.6 x 1.2	13,455	0.3 x 0.3	107,593	1' x 1'	43,575
3 x 3	4,840	0.9 x 0.9	11,960	0.5 x 0.5	40,000	1'8" x 1'8"	16,200
4 x 4	2,722	1.2 x 1.2	6,726	0.5 x 1.0	20,000	1'8" x 3'3"	8,100
4 x 5	2,178	1.2 x 1.5	5,382	0.5 x 2.0	10,000	1'8" x 6'7"	4,050
4 x 6	1,815	1.2 x 1.8	4,485	0.75 x 0.75	17,778	2'6" x 2'6"	7,200
4 x 7	1,556	1.2 x 2.1	3,845	0.75 x 1.0	13,333	2'6" x 3'3"	5,400
4 x 8	1,361	1.2 x 2.4	3,363	0.75 x 1.5	8,889	2'5" x 4'11"	3,600
4 x 9	1,210	1.2 x 2.7	2,990	1.0 x 1.0	10,000	3'3" x 3'3"	4,050
4 x 10	1,089	1.2 x 3.0	2,691	1.0 x 1.5	6,667	3'3" x 4'11"	2,700
5 x 5	1,742	1.5 x 1.5	4,304	1.0 x 2.0	5,000	3'3" x 6'6"	2,025
5 x 6	1,452	1.5 x 1.8	3,588	1.0 x 3.0	3,333	3'3" x 9'10"	1,350
5 x 7	1,245	1.5 x 2.1	3,076	1.5 x 1.5	4,444	4'11"x4'11"	1,800
5 x 8	1,089	1.5 x 2.4	2,691	1.5 x 2.0	3,333	4'11"x 6'6"	1,350
5 x 9	968	1.5 x 2.7	2,392	1.5 x 3.0	2,222	4'11"x9'10"	900
5 x 10	871	1.5 x 3.0	2,152	2.0 x 2.0	2,500	6'6" x 6'6"	1,013
6 x 6	1,210	1.8 x 1.8	2,990	2.0 x 2.5	2,000	6'6" x 8'2"	810
6 x 7	1,037	1.8 x 2.1	2,562	2.0 x 3.0	1,667	6'6" x 9'10"	675
6 x 8	908	1.8 x 2.4	2,244	2.0 x 4.0	1,250	6'6" x 13'1"	506
6 x 9	807	1.8 x 2.7	1,994	2.5 x 2.5	1,600	8'2" x 8'2"	648
6 x 10	726	1.8 x 3.0	1,794	2.5 x 3.0	1,333	8'2" x 9'10"	540
6 x 12	605	1.8 x 3.7	1,495	3.0 x 3.0	1,111	9'10"x9'10"	450
7 x 7	889	2.1 x 2.1	2,197	3.0 x 4.0	833	9'10"x13'1"	337
7 x 8	778	2.1 x 2.4	1,922	3.0 x 5.0	666	9'10"x13'1"	270
7 x 9	691	2.1 x 2.7	1,707	4.0 x 4.0	625	13'1" x 13'1"	253
7 x 10	622	2.1 x 3.0	1,537	5.0 x 5.0	400	16'5" x 16'5"	162
7 x 12	519	3.1 x 3.7	1,282				
8 x 8	681	2.4 x 2.4	1,683				
8 x 9	605	2.4 x 2.7	1,495				
8 x 10	544	2.4 x 3.0	1,344				
8 x 12	454	2.4 x 3.7	1,122				
9 x 9	538	2.7 x 2.7	1,329				
9 x 10	484	2.7 x 3.0	1,196				
9 x 12	403	2.7 x 3.7	996				
10 x 10	436	3.0 x 3.0	1,077				
10 x 12	363	3.0 x 3.7	897				
10 x 15	290	3.0 x 4.5	717				
12 x 12	302	3.7 x 3.7	746				
12 x 15	242	3.7 x 4.6	598				

<sup>a</sup> The spacing is approximated to nearest centimeter but trees per hectare = trees per acre x 2.471

<sup>b</sup> The spacing is approximated to nearest inch but trees per acre = trees per hectare x 0.405

**Table A.9**  
**Wood and Log Volume to Volume Conversion Factors**

FROM	TO						
	standard cord	solid cord	cunit	board foot	1,000 board feet	cubic foot average	cubic meters average
standard cord	1	1.6	1.28	1,536	1.536	128	3.6246
solid cord	0.625	1	0.8	960	0.96	80 <sup>a</sup>	2.2653
cunit	0.7813	1.25	1	1,200	1.2	100	2.832
board foot	0.00065	0.00104	0.00083	1	0.001	0.0833	0.0024
1,000 board feet	0.651	1.0416	0.8333	1,000	1	83.33	2.3598
cubic foot	0.0078	0.0125	0.01	12	0.012	1	0.0283
cubic meters	0.2759	0.4414	0.3531	423.77	0.4238	35.3146	1

**Source:**

[www.unitconversion.org](http://www.unitconversion.org), verified with several other sources.

**Brief Definitions of the Forestry Measures:**

A standard cord is 4 ft x 4 ft x 8 ft stack of roundwood including bark and air

A solid cord is the net volume of roundwood in a standard cord stack

A cunit is 100 cubic feet of solid wood

1 board foot (bf) is a plank of lumbar measuring 1 inch x 1 foot x 1 foot (1/12 ft<sup>3</sup>)

1000 board feet (MBF) is a standard measure used to buy and sell lumber

1 cubic foot of lumber is a 1 ft x 1 ft x 1 ft cube

1 cubic meter of lumber is a 1 m x 1 m x 1 m cube

**Notes:** The conversions in this table are only suitable for converting volume units of harvested roundwood or processed sawtimber to approximate alternative volume units, but not for estimating standing volume biomass.

<sup>a</sup> The estimate of 80 cubic feet (or 2.26 cubic meters) in a solid cord is an average value for stacked lumber and also for hardwood roundwood with bark. Values for all roundwood wood types with and without bark can range from 60 to 95 cubic feet or (1.69 to 2.69 cubic meters), depending on wood species, moisture content and other factors.

To use these conversion factors, first decide the mill type, which is based on equipment; then determine the average scaling diameter of the logs. If the equipment indicates a mill type B and the average scaling diameter is 13 inches, then look in section B, line 2. This line shows that for every thousand board feet of softwood lumber sawed, 0.42 tons of bark, 1.18 tons of chippable material, and 0.92 tons of fines are produced, green weight. Equivalent hard hardwood and soft hardwood data are also given. Converting factors for shavings are omitted as they are zero for sawmills.

**Table A.10**  
**Estimating Tons of Wood Residue per Thousand Board Feet of Lumber**  
**Produced by Sawmills, by Species and Type of Residue**

Mill Type <sup>a</sup>	Small end diameter <sup>b</sup>	Softwood <sup>c</sup>						Hard hardwood <sup>c</sup>						Soft hardwood <sup>c</sup>					
		Bark		Chippable		Fine <sup>f</sup>		Bark		Chipable		Fine		Bark		Chipable		Fine	
		G <sup>d</sup>	OD <sup>e</sup>	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD
A, B, C, H, and I	1	0.46	0.31	1.57	0.78	0.98	0.48	0.84	0.59	1.84	1.04	1.26	0.71	0.58	0.41	1.27	0.72	0.86	0.49
	2	0.42	0.29	1.18	0.58	0.92	0.45	0.72	0.51	1.53	0.87	1.34	0.76	0.50	0.35	1.06	0.60	0.91	0.52
	3	0.41	0.28	1.07	0.53	1.00	0.49	0.56	0.39	1.17	0.66	1.08	0.61	0.39	0.27	0.81	0.46	0.74	0.42
	4	0.31	0.21	0.88	0.43	0.91	0.45	0.49	0.35	1.03	0.58	1.05	0.60	0.34	0.24	0.72	0.41	0.72	0.41
D and E	1	0.29	0.20	1.57	0.78	0.90	0.45	0.84	0.59	1.84	1.04	0.92	0.52	0.58	0.41	1.27	0.72	0.63	0.36
	2	0.29	0.20	1.18	0.58	0.76	0.38	0.72	0.51	1.53	0.87	0.84	0.48	0.50	0.35	1.06	0.60	0.58	0.33
	3	0.29	0.20	1.07	0.53	0.71	0.35	0.56	0.39	1.17	0.66	0.84	0.48	0.39	0.27	0.81	0.46	0.58	0.33
	4	0.29	0.20	0.88	0.43	0.64	0.32	0.49	0.35	1.03	0.58	0.80	0.45	0.34	0.24	0.72	0.41	0.55	0.31
F	1	0.29	0.20	1.57	0.78	0.98	0.48	0.84	0.59	1.84	1.04	1.26	0.71	0.58	0.41	1.27	0.72	0.86	0.49
	2	0.29	0.20	1.18	0.58	0.92	0.45	0.72	0.51	1.53	0.87	1.34	0.76	0.50	0.35	1.06	0.60	0.91	0.52
	3	0.29	0.20	1.07	0.53	1.00	0.49	0.56	0.39	1.17	0.66	1.08	0.61	0.39	0.27	0.81	0.46	0.74	0.42
	4	0.29	0.20	0.88	0.43	0.91	0.45	0.49	0.35	1.03	0.58	1.05	0.60	0.34	0.24	0.72	0.41	0.72	0.41
G	1	0.29	0.20	1.90	0.94	0.57	0.28	0.84	0.59	2.23	1.28	0.53	0.28	0.58	0.41	1.54	0.88	0.36	0.20
	2	0.29	0.20	1.34	0.66	0.60	0.30	0.72	0.51	1.72	0.98	0.65	0.37	0.50	0.35	1.19	0.68	0.45	0.25
	3	0.29	0.20	1.17	0.58	0.61	0.30	0.56	0.39	1.29	0.73	0.72	0.41	0.39	0.27	0.89	0.51	0.50	0.28
	4	0.29	0.20	0.98	0.48	0.54	0.28	0.49	0.35	1.15	0.65	0.68	0.38	0.34	0.24	0.80	0.46	0.47	0.26

**Source:**

Ellis, Bridgette K. and Janice A. Brown, *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley Region*, Tennessee Valley Authority, August 1984.

<sup>a</sup> Mill Type: A. Circular headsaw with or without trim saw; B. Circular headsaw with edger and trim saw; C. Circular headsaw with vertical band resaw, edger, trim saw; D. Band headsaw with edger, trim saw; E. Band headsaw with horizontal band resaw, edger, trim saw; F. Band headsaw with cant gangsaw, edger, trim saw; G. Chipping head rig; H. Round log mill; I. Scragg mill.

<sup>b</sup> Average small-end log (scaling) diameter classes: 1. 5-10 inches; 2. 11-13 inches; 3. 14-16 inches; 4. 17 inches and over.

<sup>c</sup> See Appendix A for species classification, i.e., softwood, hard hardwood, and soft hardwood.

<sup>d</sup> G = green weight, or initial condition, with the moisture content of the wood as processed

<sup>e</sup> OD = Oven Dry. It is the weight at zero percent moisture.

<sup>f</sup> Fine is sawdust and other similar size material.

**Table A.11**  
**Estimating Tons of Wood Residue per Thousand Board Feet of Wood Used for Selected Products**

Type of Plant	Softwood <sup>a</sup>							
	Bark	% MC	Chipable <sup>b</sup>	% MC	Shavings	% MC	Fine <sup>c</sup>	%MC
Planing mill	-	-	0.05	19	0.42	19	-	-
Wood chip mill <sup>d</sup>	0.60	50	-	-	-	-	-	-
Wooden furniture frames	-	-	0.22	12	0.25	12	0.05	12
Shingles & cooperage stock	0.42	50	1.29	100	-	-	1.01	100
Plywood	-	-	0.13	9	-	-	0.21	9
Veneer	0.42	50	1.77	100	-	-	-	-
Pallets and skids	-	-	0.42	60	0.21	60	0.07	60
Log homes	-	-	0.17	80	-	-	0.05	80
Untreated posts, poles, and pilings	0.46	50	0.40	100	-	-	0.05	100
Particleboard	0.60	60	-	-	-	-	0.21	6
Pulp, paper, and paperboard	0.60	70	-	-	-	-	-	-
Type of Plant	Hard hardwood <sup>a</sup>							
	Bark	% MC	Chipable <sup>b</sup>	% MC	Shavings	% MC	Fine <sup>c</sup>	%MC
Planing mill	-	-	0.06	19	0.54	19	-	-
Wood chip mill	0.90	60	-	-	-	-	-	-
Hardwood flooring	-	-	0.12	6	0.57	6	-	-
Wooden furniture frames	-	-	0.31	9	0.36	9	0.07	9
Shingles & cooperage stock	0.56	60	1.66	70	-	-	1.47	70
Plywood	-	-	0.16	9	-	-	0.26	9
Veneer	0.72	60	2.70	70	-	-	-	-
Pallets and skids	-	-	0.50	60	0.25	60	0.08	60
Pulp, paper, and paperboard	0.90	60	-	-	-	-	-	-
Type of Plant	Soft hardwood <sup>a</sup>							
	Bark	% MC	Chipable <sup>b</sup>	% MC	Shavings	% MC	Fine <sup>c</sup>	%MC
Planing mill	-	-	0.04	19	0.40	19	-	-
Wood chip mill	0.62	88	-	-	-	-	-	-
Wooden furniture frames	-	-	0.22	9	0.26	9	0.05	9
Plywood	-	-	0.13	9	-	-	0.21	9
Veneer	0.50	88	2.13	95	-	-	-	-
Pallets and skids	-	-	0.34	60	0.17	60	0.06	60
Particleboard	0.60	60	-	-	-	-	0.21	6
Pulp, paper, and paperboard	0.62	88	-	-	-	-	-	-

**Source:**

Ellis, Bridgette K. and Janice A. Brown, *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley Region*, Tennessee Valley Authority, August 1984.

**Notes:** For shingles and cooperage stock the table indicates that for every thousand board feet of softwood logs used, 1.29 tons of chippable material could be expected, with an average moisture content (MC) of 100%, based on oven-dry weight. If the Average MC of the wood used is greater or less than 100%, proportionally greater or lesser weight of material could be expected.

<sup>a</sup> For definitions of species, see next page

<sup>b</sup> Chippable is material large enough to warrant size reduction before being used by the paper, particleboard, or metallurgical industries.

<sup>c</sup> Fines are considered to be sawdust or sanderdust.

<sup>d</sup> For chipping mills with debarkers only

**Table A.12**  
**Area and Length Conversions**

<b>Area</b>		
<b>Multiply</b>	<b>by</b>	<b>To Obtain</b>
acres (ac) <sup>a</sup>	0.4047	hectares
hectares (ha)	2.4710	acres
hectares (ha)	0.0039	square miles
hectares (ha)	10000	square meters
square kilometer (km <sup>2</sup> )	247.10	acres
square kilometer (km <sup>2</sup> )	0.3861	square miles
square kilometer (km <sup>2</sup> )	100	hectares
square mile (mi <sup>2</sup> )	258.9990	hectares.
square mile (mi <sup>2</sup> )	2.5900	square kilometers
square mile (mi <sup>2</sup> )	640	acres
square yards (yd <sup>2</sup> )	0.8361	square meters
square meters (m <sup>2</sup> )	1.1960	square yards
square foot (ft <sup>2</sup> )	0.0929	square meters
square meters (m <sup>2</sup> )	10.7639	square feet
square inches (in <sup>2</sup> )	6.4516	square centimeters (exactly).
square decimeter (dm <sup>2</sup> )	15.5000	square inches
square centimeters (cm <sup>2</sup> )	0.1550	square inches
square millimeter (mm <sup>2</sup> )	0.0020	square inches
square feet (ft <sup>2</sup> )	929.03	square centimeters
square rods (rd <sup>2</sup> ), sq pole, or sq perch	25.2930	square meters

<b>Length</b>		
<b>Multiply</b>	<b>by</b>	<b>To Obtain</b>
miles (mi)	1.6093	kilometers
miles (mi)	1,609.34	meters
miles (mi)	1,760.00	yards
miles (mi)	5,280.00	feet
kilometers (km)	0.6214	miles
kilometers (km)	1,000.00	meters
kilometers (km)	1,093.60	yards
kilometers (km)	3,281.00	feet
feet (ft)	0.3048	meters
meters (m)	3.2808	feet
yard (yd)	0.9144	meters
meters (m)	1.0936	yards
inches (in)	2.54	centimeters
centimeters (cm)	0.3937	inches

**Source:**

National Institute of Standards and Technology, General Tables of Units and Measurements,  
[http://ts.nist.gov/WeightsAndMeasures/Publications/upload/h4402\\_appenc.pdf](http://ts.nist.gov/WeightsAndMeasures/Publications/upload/h4402_appenc.pdf).

<sup>a</sup> An acre is a unit of area containing 43,560 square feet. It is not necessarily square, or even rectangular. If a one acre area is a perfect square, then the length of a side is equal to the square root of 43,560 or about 208.71 feet.



**Table A.13**  
**Mass Units and Mass per Unit Area Conversions**

<b>Mass</b>		
<b>Multiply</b>	<b>by</b>	<b>To Obtain</b>
ounces (oz)	28.3495	grams
grams (gm)	0.0353	ounces
pounds (lbs)	0.4536	kilograms
pounds (lbs)	453.6	grams
kilograms (kg)	2.2046	pounds
kilograms (kg)	0.0011	U.S. or short tons,
metric tons or tonne (t) <sup>a</sup>	1	megagram (Mg)
metric tons or tonne (t)	2205	pounds
metric tons or tonne (t)	1000	kilograms
metric tons or tonne (t)	1.102	short tons
metric tons or tonne (t)	0.9842	long tons
U.S. or short tons, (ts)	2000	pounds
U.S. or short tons, (ts)	907.2	kilograms
U.S. or short tons, (ts)	0.9072	megagrams
U.S. or short tons, (ts)	0.8929	Imperial or long tons
Imperial or long tons (tl)	2240	pounds
Imperial or long tons (tl)	1.12	short tons
Imperial or long tons (tl)	1016	kilograms
Imperial or long tons (tl)	1.016	megagrams

<b>Mass per Unit Area</b>		
<b>Multiply</b>	<b>by</b>	<b>To Obtain</b>
megagram per hectare (Mg ha <sup>-1</sup> )	0.4461	short tons per acre
kilograms per square meter (kg m <sup>-2</sup> )	4.461	short tons per acre
tons (short US) per acre (t ac <sup>-1</sup> )	2.2417	megagram per hectare
tons (short US) per acre (t ac <sup>-1</sup> )	0.2241	kilograms per square meter
kilograms per square meter (kg m <sup>-2</sup> )	0.2048	pounds per square foot
pounds per square foot (lb ft <sup>2</sup> )	4.8824	kilogram per square meter
kilograms per square meter (kg m <sup>-2</sup> )	21.78	short tons per acre
kilogram per hectare (kg ha <sup>-1</sup> )	0.892	pounds per acre
pounds per acre (lb ac <sup>-1</sup> )	1.12	kilogram per hectare

**Source:**

Web sites [www.gordonengland.co.uk/conversion](http://www.gordonengland.co.uk/conversion) and [www.convert-me.com/en/convert](http://www.convert-me.com/en/convert) and the Family Farm Series Publication, "Vegetable Crop Production" at Web site [www.sfc.ucdavis.edu/pubs/Family\\_Farm\\_Series/Veg/Fertilizing/appendix.html#tables](http://www.sfc.ucdavis.edu/pubs/Family_Farm_Series/Veg/Fertilizing/appendix.html#tables).

<sup>a</sup> The proper SI unit for a metric ton or tonne is megagram (MG) however "t" is commonly used in practice as in dt ha<sup>-1</sup> for dry ton per hectare. Writers in the United States also normally use "t" for short ton as in dt ac<sup>-1</sup> for dry ton per acre, so noting the context in the interpretation of "t" is important.

**Table A.14**  
**Distance and Velocity Conversions**

<hr/> 1 inch (in) = 0.0833 ft = 0.0278 yd = 2.54 cm = 0.0254 m	1 centimeter (cm) = 0.3937 in = 0.0328 ft = 0.0109 yd = 0.01 m
1 foot (ft) = 12.0 in. = 0.3333 yd = 30.48 cm = 0.3048 m	1 meter (m) = 39.3700 in = 3.2808 ft = 1.0936 yd = 100 cm
1 mile (mi) = 63360 in. = 5280 ft = 1760 yd = 1609 m = 1.609 km	1 kilometer (km) = 39370 in. = 3281 ft = 1093.6 yd = 0.6214 mile = 1000 m

---

$$1 \text{ in/hr} = 2.54 \text{ cm/hr}$$

$$1 \text{ cm/hr} = 0.3937 \text{ in/hr}$$

$$1 \text{ ft/sec} = 0.3048 \text{ m/s} = 0.6818 \text{ mph} = 1.0972 \text{ km/h}$$

$$1 \text{ m/sec} = 3.281 \text{ ft/s} = 2.237 \text{ mph} = 3.600 \text{ km/h}$$

$$1 \text{ km/h} = 0.9114 \text{ ft/s} = 0.2778 \text{ m/s} = 0.6214 \text{ mph}$$

$$1 \text{ mph} = 1.467 \text{ ft/s} = 0.4469 \text{ m/s} = 1.609 \text{ km/h}$$

---

**Source:**

Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

**Table A.15**  
**Capacity, Volume and Specific Volume Conversions<sup>a</sup>**

**Capacity and Volume**

1 U.S. gallon (gal)	= 3.785 liters (L)	1 liter (L)	= 0.2642 US gal
	= 4 US quarts (qt)		= 0.22 UK gal
	= 0.8327 UK gallon (gal)		= 1.056 US qt
	= 0.0238 barrels oil (bbl)		= 0.00629 bbl (oil)
	= 0.0039 cubic meters (m <sup>3</sup> )		= 61.02 in <sup>3</sup>
	= 0.1337 cubic feet (ft <sup>3</sup> )		= 0.03531 ft <sup>3</sup>
	= 231 cubic inches (in <sup>3</sup> )		= 0.001 m <sup>3</sup>
1 imperial (UK) gallon (gal)	= 4.546 liters	1 barrel (bbl) oil	= 158.97 L
	= 4.803 US qt		= 168 US qt
	= 1.201 US gal		= 42 US gal
	= 0.0286 bbl (oil)		= 34.97 UK gal
	= 0.0045 m <sup>3</sup>		= 0.15897 m <sup>3</sup>
	= 0.1605 ft <sup>3</sup>		= 5.615 ft <sup>3</sup>
	= 277.4 in. <sup>3</sup>		= 9702 in. <sup>3</sup>
1 cubic meter (m <sup>3</sup> )	= 264.172 US gal	1 cubic foot (ft <sup>3</sup> )	= 7.4805 US gal
	= 1000 L		= 28.3168 L
	= 1056 US qt		= 29.9221 US qt
	= 6.2898 bbl (oil)		= 0.1781 bbl (oil)
	= 35.3145 ft <sup>3</sup>		= 0.0283 m <sup>3</sup>
	= 1.3079 yd <sup>3</sup>		= 0.037 yd <sup>3</sup>
1 cubic centimeter (cm <sup>3</sup> )	= 0.061 in <sup>3</sup>	1 cubic inches (in <sup>3</sup> )	= 16.3872 cm <sup>3</sup>
1 Liter (L) dry volume	= 1.8161 US pint (pt)	1 US bushel	= 64 US pt
	= 0.908 US qt		= 32 US qt
	= 0.1135 US peck (pk)		= 35.239 L
	= 0.1099 UK pk		= 4 US pk
	= 0.0284 US bushel (bu)		= 3.8757 UK pk
	= 0.0275 UK bu		= 0.9700 UK bu
	= 0.0086 US bbl dry		= 0.3947 US bbl dry
1 barrell (dry)	= 13.1248 US pk	1 barrell (dry)	= 12.7172 UK pk
	= 3.2812 US bu		= 3.1793 UK bu

<sup>a</sup> Forestry unit relationships are provided in Table A.9

**Specific Volume**

1 US gallon per pound (gal/lb)	= 0.8326 UK gal/lb	1 liter per kilogram (L/kg)	= 0.0997 UK gal/lb
	= 0.1337 ft <sup>3</sup> /lb		= 0.1118 US gal/lb
	= 8.3454 L/kg		= 0.016 ft <sup>3</sup> /lb
	= 0.0083 L/g		= 0.0353 ft <sup>3</sup> /kg
	= 0.0083 m <sup>3</sup> /kg		= 1 m <sup>3</sup> /kg
	= 8.3451 cm <sup>3</sup> /g		= 1000 cm <sup>3</sup> /g

**Source:**

Web sites [www.gordonengland.co.uk/conversion/power.html](http://www.gordonengland.co.uk/conversion/power.html) and [www.unitconversion.org](http://www.unitconversion.org) were used to make or check conversions.

<sup>a</sup> Forestry unit relationships are provided in Table A.9 .

**Table A.16**  
**Power Unit Conversions**

<b>Per second basis</b>						
<b>FROM</b>	<b>TO</b>					
	hp	hp-metric	kW	$\text{kJ s}^{-1}$	$\text{Btu}_{\text{IT}} \text{ s}^{-1}$	$\text{kcal}_{\text{IT}} \text{ s}^{-1}$
Horsepower	1	1.014	0.746	0.746	0.707	0.1780
Metric horsepower	0.986	1	0.736	0.736	0.697	0.1757
Kilowatt	1.341	1.360	1	1	0.948	0.2388
kilojoule per sec	1.341	1.359	1	1	0.948	0.2388
$\text{Btu}_{\text{IT}}$ per sec	1.415	1.434	1.055	1.055	1	0.2520
Kilocalories <sub>IT</sub> per sec	5.615	5.692	4.187	4.187	3.968	1

<b>Per hour basis</b>						
<b>FROM</b>	<b>TO</b>					
	hp	hp- metric	kW	$\text{J hr}^{-1}$	$\text{Btu}_{\text{IT}} \text{ hr}^{-1}$	$\text{kcal}_{\text{IT}} \text{ hr}^{-1}$
Horsepower	1	1.014	0.746	$268.5 \times 10^4$	2544	641.19
Metric horsepower	0.986	1	0.736	$265.8 \times 10^4$	2510	632.42
kilowatt	1.341	1.360	1	$360 \times 10^4$	3412	859.85
Joule per hr	$3.73 \times 10^{-7}$	$3.78 \times 10^{-7}$	$2.78 \times 10^{-7}$	1	$9.48 \times 10^{-4}$	$2.39 \times 10^{-4}$
$\text{Btu}_{\text{IT}}$ per hr	$3.93 \times 10^{-4}$	$3.98 \times 10^{-4}$	$2.93 \times 10^{-4}$	1055	1	0.2520
Kilocalories <sub>IT</sub> per hr	$1.56 \times 10^{-3}$	$1.58 \times 10^{-3}$	$1.163 \times 10^{-3}$	4187	3.968	1

**Sources:**

[www.unitconversion.org/unit\\_converter/power.html](http://www.unitconversion.org/unit_converter/power.html) and  
[www.gordonengland.co.uk/conversion/power.html](http://www.gordonengland.co.uk/conversion/power.html) were used to make conversions.

**Note:** The subscript "IT" stands for International Table values, which are only slightly different from thermal values normally subscripted "th". The "IT" values are most commonly used in current tables and generally are not subscripted, but conversion calculators usually include both.

**Table A.17**  
**Small Energy Units and Energy per Unit Weight Conversions**

Energy Units					
FROM	TO				
	MJ	J	k W h	Btu <sub>IT</sub>	cal <sub>IT</sub>
megajoule (MJ)	1	1 x 10 <sup>6</sup>	0.278	947.8	238845
joule (J) <sup>a</sup>	1 x 10 <sup>-6</sup>	1	0.278 x 10 <sup>-6</sup>	9.478 x 10 <sup>-4</sup>	0.239
Kilowatt hours (k W h)	3.6	3.6 x 10 <sup>6</sup>	1	3412	859845
Btu <sub>IT</sub>	1.055 x 10 <sup>-3</sup>	1055.055	2.93 x 10 <sup>-4</sup>	1	251.996
calorie <sub>IT</sub> (cal <sub>IT</sub> )		4.186	1.163 x 10 <sup>-6</sup>	3.97 x 10 <sup>-3</sup>	1
Energy per Unit Weight					
FROM	TO				
	J kg <sup>-1</sup>	kJ kg <sup>-1</sup>	cal <sub>IT</sub> g <sup>-1</sup>	Btu <sub>IT</sub> lb <sup>-1</sup>	
joule per kilogram ( J kg <sup>-1</sup> )	1	0.001	2.39 x 10 <sup>-4</sup>	4.299 x 10 <sup>-4</sup>	
kilojoules per kilogram( kJ kg <sup>-1</sup> )	1000	1	0.2388	0.4299	
calorie <sub>th</sub> per gram (cal <sub>IT</sub> g <sup>-1</sup> )	4186.8	4.1868	1	1.8	
Btu <sub>IT</sub> per pound (Btu <sub>IT</sub> lb <sup>-1</sup> )	2326	2.326	0.5555	1	

**Commonly used related energy unit conversions:**

1 Quadrillion Btu's (Quad) = 1 x 10<sup>15</sup> Btu = 1.055 Exajoules (EJ) = 1.055 x 10<sup>18</sup> J

1 Million Btu's (MMbtu) = 1 x 10<sup>6</sup> Btu = 1.055 Gigajoules (GJ) = 1.055 x 10<sup>9</sup> J

1000 Btu per pound x 2000 lbs per ton = 2 MMBtu per ton = 2.326 GJ per Mg, e.g.,

8500 Btu per pound (average HHV of wood) = 17 MMBtu per ton = 19.8 GJ per Mg

**Sources:**

[www.gordonengland.co.uk/conversion/power.html](http://www.gordonengland.co.uk/conversion/power.html) and

[www.convert-me.com/en/convert/power](http://www.convert-me.com/en/convert/power) and

[www.unitconversion.org/unit\\_converter/fuel-efficiency-mass](http://www.unitconversion.org/unit_converter/fuel-efficiency-mass) were used to make or check conversions.

**Note:** The subscript "IT" stands for International Table values, which are only slightly different from thermal values normally subscripted "th". The "IT" values are most commonly used in current tables and generally are not subscripted, but conversion calculators usually include both.

<sup>a</sup> One joule is the exact equivalent of one Newton meter (Nm) and one Watt second.



**Table A.18**  
**Large Energy Unit Conversions**

<b>To:</b>	<b>Terajoules</b>	<b>Giga-calories</b>	<b>Million tonnes of oil equivalent</b>	<b>Million Btu</b>	<b>Gigawatt-hours</b>
<b>From:</b>	<i>multiply by:</i>				
<b>Terajoules</b>	1	238.8	$2.388 \times 10^{-5}$	947.8	0.2778
<b>Gigacalories</b>	$4.1868 \times 10^{-3}$	1	$10^{-7}$	3.968	$1.163 \times 10^{-3}$
<b>Million tonnes of oil equivalent</b>	$4.1868 \times 10^4$	107	1	$3.968 \times 10^7$	11,630
<b>Million Btu</b>	$1.0551 \times 10^{-3}$	0.252	$2.52 \times 10^{-8}$	1	$2.931 \times 10^{-4}$
<b>Gigawatt-hours</b>	3.6	860	$8.6 \times 10^{-5}$	3412	1

**Source:**

Davis, S.C., et al., *Transportation Energy Data Book: Edition 27*, Appendix B.7. ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, TN. 2008

**Table A.19**  
**Alternative Measures of Greenhouse Gases**

1 pound methane, measured in carbon units (CH <sub>4</sub> )	=	1.333 pounds methane, measured at full molecular weight (CH <sub>4</sub> )
1 pound carbon dioxide, measured in carbon units (CO <sub>2</sub> -C)	=	3.6667 pounds carbon dioxide, measured at full molecular weight (CO <sub>2</sub> )
1 pound carbon monoxide, measured in carbon units (CO-C)	=	2.333 pounds carbon monoxide, measured at full molecular weight (CO)
1 pound nitrous oxide, measured in nitrogen units (N <sub>2</sub> O-N)	=	1.571 pounds nitrous oxide, measured at full molecular weight (N <sub>2</sub> O)

**Source:**

Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.9, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

**Table A.20**  
**Fuel Efficiency Conversions**

MPG	Miles/liter	Kilometers/L	L/100 kilometers
10	2.64	4.25	23.52
15	3.96	6.38	15.68
20	5.28	8.50	11.76
25	6.60	10.63	9.41
30	7.92	12.75	7.84
35	9.25	14.88	6.72
40	10.57	17.00	5.88
45	11.89	19.13	5.23
50	13.21	21.25	4.70
55	14.53	23.38	4.28
60	15.85	25.51	3.92
65	17.17	27.63	3.62
70	18.49	29.76	3.36
75	19.81	31.88	3.14
80	21.13	34.01	2.94
85	22.45	36.13	2.77
90	23.77	38.26	2.61
95	25.09	40.38	2.48
100	26.42	42.51	2.35
105	27.74	44.64	2.24
110	29.06	46.76	2.14
115	30.38	48.89	2.05
120	31.70	51.01	1.96
125	33.02	53.14	1.88
130	34.34	55.26	1.81
135	35.66	57.39	1.74
140	36.98	59.51	1.68
145	38.30	61.64	1.62
150	39.62	63.76	1.57
Formula	MPG/3.785	MPG/[3.785/1.609]	235.24/MPG

**Source:**

Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.13, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

**Table A.21**  
**SI Prefixes and Their Values**

	Value	Prefix	Symbol
One million million millionth	$10^{-18}$	atto	a
One thousand million millionth	$10^{-15}$	femto	f
One million millionth	$10^{-12}$	pico	p
One thousand millionth	$10^{-9}$	nano	n
One millionth	$10^{-6}$	micro	$\mu$
One thousandth	$10^{-3}$	milli	m
One hundredth	$10^{-2}$	centi	c
One tenth	$10^{-1}$	deci	d
One	$10^0$		
Ten	$10^1$	deca	da
One hundred	$10^2$	hecto	h
One thousand	$10^3$	kilo	k
One million	$10^6$	mega	M
One billion <sup>a</sup>	$10^9$	giga	G
One trillion <sup>a</sup>	$10^{12}$	tera	T
One quadrillion <sup>a</sup>	$10^{15}$	peta	P
One quintillion <sup>a</sup>	$10^{18}$	exa	E

**Source:**

Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.14, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

---

<sup>a</sup> Care should be exercised in the use of this nomenclature, especially in foreign correspondence, as it is either unknown or carries a different value in other countries. A "billion," for example, signifies a value of  $10^{12}$  in most other countries.

**Table A.22**  
**Metric Units and Abbreviations**

Quantity	Unit name	Symbol
Energy	joule	J
Specific energy	joule/kilogram	J/kg
Specific energy consumption	joule/kilogram•kilometer	J/(kg•km)
Energy consumption	joule/kilometer	J/km
Energy economy	kilometer/kilojoule	km/kJ
Power	kilowatt	kW
Specific power	watt/kilogram	W/kg
Power density	watt/meter <sup>3</sup>	W/m <sup>3</sup>
Speed	kilometer/hour	km/h
Acceleration	meter/second <sup>2</sup>	m/s <sup>2</sup>
Range (distance)	kilometer	km
Weight	kilogram	kg
Torque	newton•meter	N•m
Volume	meter <sup>3</sup>	m <sup>3</sup>
Mass; payload	kilogram	kg
Length; width	meter	m
Brake specific fuel consumption	kilogram/joule	kg/J
Fuel economy (heat engine)	liters/100 km	L/100 km

**Source:**

Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.15, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

**Table A.23**  
**Cost per Unit Conversions**

Multiply	by	To Obtain
\$/ton	1.1023	\$/Mg
\$/Mg	0.9072	\$/ton
\$/Mbtu	0.9407	\$/GJ
\$/GJ	1.0559	\$/Mbtu