How much heat is there in one pound of wood?

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1) Species

It is common knowledge that "there is much more heat in hardwood than there is in softwood." This is true enough on a volume basis. However, on a weight basis all species have about the same heat content. This is because the ultimate chemical composition is approximately the same for all varieties.

This table is based on zero moisture content:

SPECIES	SP.GR.	WT. PER CU. FT.			
		SOLID	1/4 VOIDS	3/8 VOIDS	1/2 VOIDS
MAPLE - SUGAR	0.63	39.4	29.8	29.6	19.7
ASH - WHITE	0.62	38.7	29.0	24.2	19.4
BIRCH	0.62	38.7	29.0	24.2	19.4
APPLE					
MAPLE - SILVER	0.47	29.3	22.0	18.3	14.6
MAPLE - MANITOBA					
PINE - RED	0.46	28.7	21.5	17.9	14.4
POPLAR - YELLOW	0.42	26.2	19.7	16.4	13.1
SPRUCE - WHITE	0.40	25.0	18.5	15.5	12.5
BASSWOOD	0.38	23.7	17.8	14.8	11.8
PINE - WHITE	0.35	21.9	16.4	13.6	10.9
WILLOW	o.28	17.5	13.1	10.9	
CEDAR - WHITE	0.31	19.3	14.5	12.1	9.7

Note that maple in a solid log may weigh four times as much as craftily piled willow occupying the same amount of space.

2) Chemical composition

The ultimate chemical composition of wood is approximately -

Carbon	49%	
Hydrogen	6%	
Oxygen	44%	For almost all species
Ash	1%	
Total	100%	

However, these three elements are combined into an innumerable array of compounds, some of which are quite simple while others are unbelievably complex. These compounds, known as carbohydrates, are grouped into three classifications - cellulose, lignin, resins.

3) Pyrolysis

When wood starts to burn the cellulose, lilgnin and resins begin to break down into simpler compounds which form and reform into a new array of organic chemicals which leave the wood in the form of gases and/or droplets of liquid. If these are ignited in the presence of enough air, they burn. However, if the temperature in the firebox is not high enough, or if they are starved for air, as in an air-tight stove, they move into the chimney and, if the chimney is warm enough, they escape unburned and unused into the atmosphere. Because many of them are carcinogens (i.e. cancer producing substances) become undesirable air pollutants.

A recent newspaper column, quoting a U.S. source discussing "air-tight" wood burning stoves stated that they were becoming a major source of air pollutants because at least fourteen of the compounds found in the effluent had been identified as suspected carcinogens.

Of course, if the chimney is cool enough condensation takes place and the resulting build-up on the walls is fuel burned in chimney fires.

This process of heating wood in the absence of air is called pyrolysis, or carbonization. The final product left after all the gases and liquids have been expelled is charcoal which is almost pure carbon.

The bulk of the products are driven off between 540F and 900F. Slow heating yields about 50% charcoal while very quick heating of small pieces yields as low as 13%. This means that an injudicious operator may send from one half to two thirds of his fuel up the chimney to create at least a nuisance if not a health hazard elsewhere - to say nothing of the waste.

A partial list of chemicals driven off during pyrolysis includes such names as:

formic acid	furfural
acetic acid	phenols
methyl alcohol	creosote
ethyl alcohol	ammonia
formaldehyde	carbon monoxide
acetone	resins
	waxes

4) Ignition temperatures

Material	Ignition Temp.
Hydrogen	1000 F
Carbon Monoxide	1100
Methane	1200
Acetic Acid	1000
Formaldehyde	800
Pine Tar	670
Charcoal	as low as 300

This table shows that a reasonably high temperature is needed to ignite many of the products that are driven from wood when it is heated.

It is interesting to note in passing that although wood normally ignites spontaneously at a temperature between 600 and 700F this temperature may be lowered significantly by heating and cooling repeatedly in a flameless environment.

Temperatures as low as 250F have actually been reported for spontaneous combustion but this was after a great many heating and cooling cycles.

5) Combustion

The fundamental chemical equations for the combustion of wood are very simple:

$2H_2 + O_2$ --$2H_20$

$C + O_2$ --CO_2

The trick is to supply enough heat and oxygen (air) in a sufficiently turbulent state to persuade the individual atoms of hydrogen and carbon to leave their comfortable quarters in the complex hydrocarbons and to unite with the free atoms of oxygen, and thereby to release, the enery from the sun that was stored during the growth of the wood.

Heat of Combustion

A table of combustion reactions shows -

H20	+ 1/2O2	--H2O	and 62000 BTUs per lb.
C	+ O2	--CO2	and 14600 BTU's per lb.

One would therefore expect that the heating value of

$CH_4 + 2O_2$ --$CO_2 + 2H_2O$ could be calculated as follows

Molecular weight of C	= 12	1 C = 12 = 75%
Molecular weight of H	= 1	4 H = 4 = 25%
Molecular weight of CH4	= 16	CH4= 16 = 100%

1 lb. of methane should give

0.75x14,600 = 10,940 BTUs

\+ 0.25x62,000 = 15,500 BTUs

for a total of 26,440 BTUs

But the table shows the heating value of methane = 23,800 BTUs

Similarly with wood -

1 lb of wood is 49% C, and

0.49 x 14,600 = 7150

and 6% H, and

0.06 x 62000 = 3720

Therefore from one lb of wood one would expect 10,870 BTUs

However, although there does not seem to be complete agreement, the generally accepted value for the *gross heating value* of "oven dry", i.e. zero moisture, wood is 8600 BTUs per lb. The difference is due to something called the *law of mass action* - the reluctance of the last few molecules of a compound to break up into its elements so that these atoms can join with others to form new compounds - in our case CO_2 and H_2O.

Net Heating Value

The formula $H_2 + 1/2\ O_2$ --H_2O means, among other things that 2 lbs of hydrogen combines with 16 lbs. of oxygen to produce 18 lbs of water. Therefore, 1 lb of wood which is 0.06 lbs of hydrogen produces 0.54 lbs. of water. This water is in the form of steam and it is not practical to condense it, so it goes up the chimney, carrying its *heat of vaporization* with it.

The heat of vaporization of water is 1058.2 BTU/lb

0.54 x 1058.2 = 570 BTU/lb.

Recall that the Gross Heating Value = 8600 BTU/lb

Less heat of vaporization of steam produced from combustion of hydrogen = 570

Net Heating Value of 1 lb of dry wood = 8030 BTU

Moisture Content of Wood

Wood is a *hygroscopic* material (I always thought it was hydroscopic, but the dictionary says hygroscopic), meaning that it readily absorbs and retains moisture.

In normal storage conditions it never reaches zero moisture or an oven dry condition; its moisture content gradually approaches an euilibrium value which depends on storage conditions and the relative humidity of the atmosphere. By normal storage we mean shed or open shed or covering that allows atmospheric air to circulate freely around it but protects it from direct rain and snow and maybe heavyt dew.

Strictly speaking the moisture content is wt. of sample from storage - wt of sample in oven dry condition / oven dry wt.

However, it is often taken as (100 lbs of wood taken from storage) minus (the wt. of the same sample in an oven dry condition). So before you get in an argument be sure you know what formula is being used.

If one assumes a 15% moisture content then on a dry wt. basis -

The dry wt. + 15% of the dry wt. = 100

The dry wt. x (1 + 0.15) =100

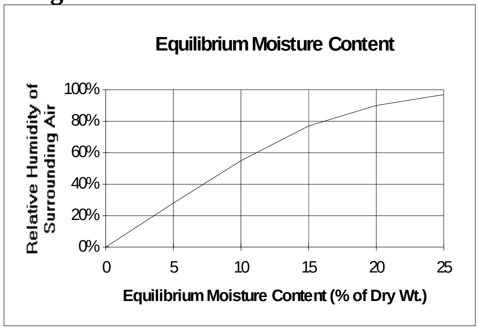
The dry wt. = 100/1. = 87 lbs.

On a total wt. basis -

The dry wt. = 100 - 15% of 100 = 85 lbs.

This is important in a laboratory but of no great moment on the farm.

Heating Value (per lb. of wood) versus Moisture Content on a Dry Weight Basis:



Here at Aurora I assume an average relative humidity of about 80% which gives a moisture of about 15% and a corresponding new heat available of 6845 BTUs per lb. of stored wood.

Excess Air

By this we mean the air that is admitted into the combustion chamber in excess of the amount theoretically required for complete combustion.

Excess air aids combustion but it steals heat and carries it up the chimney.

Without instruments for flue gas analysis it is impossible to know how much excess air a stove is using.

There is of course a lower limit, below which complete combustion is unlikely and if very low complete combustion is impossible.

The minimum amount for practically complete combustion depends on several variables, each of which is apt to vary with each installation. A separate test should be made for every case.

30% is I believe a low average figure so we will use it to show how much heat it takes away.

1 lb. of carbon requires 11.52 lb. of air for complete combustion.

0.49 lb of carbon requires 11.52 x 0.49 = 5.65 lb. of air for complete combustion.

1 lb. of hydrogen requires 34.56 lb

0.06 lb of hydrogen requires 34.56 x 0.06 = 2.07 lb.

Therefore, 1 lb of wood requires 7.72 lb. of air.

30% excess air = 2.32 lbs. (A purist would take into account the oxygen that is in the wood.)

Assume (average stack temp - temp of burning air) = 200F.

Assume Specific Heat of air = 0.24 BTUs/lb

2.32 lbs. x 0.24 BTUs/lb x 200F = 111BTUs

This doesn't look like an appreciable amount but 100% excess would be 370 and of course a higher chimney temperature would also increase the loss.

Anyway it appears wise to use enough excess air to ensure as complete combustion as possible and this cannot be done by closing the drafts as in an airtight model.

6) Other losses or Deficiencies

Summary - How Much Heat From 1 lb of Wood?

Moisture %	Wt of Sample	Wt at Oven Dry Condition		In 1 lb. Sample			
		Wood	Water	Low Ht. Value	Ht. of Vap. of Water	Net Heat Available	% of Max
0	1 lb.	1.00	0	8030	-	8030	100.0
10	1 lb.	0.91	0.09	7300	95	7205	89.7
20	1 lb.	0.83	0.17	6660	180	6480	80.7
30	1 lb.	0.77	0.23	6170	245	5925	73.8
40	1 lb.	0.71	0.29	5700	305	5395	67.2
50	1 lb.	0.66	0.34	5300	360	4940	61.5
60	1 lb.	0.62	0.38	4960	400	4560	56.8
70	1 lb.	0.59	0.41	4740	435	4305	53.6
80	1 lb.	0.56	0.44	4500	465	4035	50.2
90	1 lb.	0.53	0.57	4250	495	3755	46.8
100	1 lb.	0.50	0.50	4015	530	3485	43.3

Other Losses or Deficiencies

a) up the chimney - in the ideal case, i.e. complete combustion, the only materials going up the chimney besides excess air would be CO_2, nitrogen and steam. Of course, this is not likely and may be impossible but whatever goes up must carry enough heat with it to prevent condensation.

b) Unburned Material - Except for unburned crumbs and pieces of carbon or charcoal, that fall through the grate and into the ashbox, which is really negligible the only other unburned material is in the form of gases or vapor and have been mentioned elsewhere (ed. note: these days we would add PM, particulate matter, ie., droplets of tar around 1/20,000 inch in size known as "woodsmoke").

= large variations

Probably as good a figure as any and the one I use for masonry heaters burning decently prepared wood stored under cover is **6,000 BTU's per lb.**

1) Theoretical, but essentially impossible total = 10,800 BTU
2) Practicable, generally accepted **Gross Heating Value** = 8,600 BTU
3) Reduce due to steam produced by burning hydrogen, **Net Heating Value** = 8,030 BTU
4) Reduce due to moisture content - see table and make your choice, in this case = 6,845 BTU
5) Excess air - see discussion and make your choice = 6,700 BTU