A Look at the Details of CO_2 Emissions from burning Wood vs. Coal

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FutureMetrics has published several papers regarding the efficacy of the Manomet Study[2] vis-à-vis the methodology for modeling the carbon cycle. Our previous critiques were centered on the assumptions regarding carbon debt and the timing of the carbon recapture by growing sustainably managed forests.

In one of our papers we accept the premise at the foundation of the Manomet work; that the combustion of wood releases more CO_2 than the combustion of coal by 34.6%[3]. We decided to look at that assumption more closely. What we have found is very interesting and proves us wrong for assuming that the Manomet data was correct.

Table 1 below shows the CO_2 emissions per million BTU for a variety of wood species and Table 2 shows the data for four grades of coal. Although wood species densities vary quite a lot, the output of CO_2 per million BTU (MMBTU) is quite consistent. Coal started its life a long time ago as biomass. And, it turns out, on a dry basis, coal and wood yield very similar results in terms of the CO_2 produced (in terms of kilograms of CO_2 per unit of potential energy).

The results of our analysis shows that wood is generally about the same or perhaps a bit lower in CO_2 emissions on a dry basis (zero moisture content).

Of course wood does not have zero moisture content (MC). But as it turns out neither does coal.

The typical moisture content of coal is:

- Anthracite Coal : 2.8% - 16.3% by weight
- Bituminous Coal : 2.2% - 15.9% by weight
- Lignite Coal : 39% or more by weight

It is the water in fuel that causes its CO_2 emissions to increase over the dry weight basis. The underlying cause that drives this is “the enthalpy of vaporization”. In simple terms, it takes energy to evaporate the water in the wood or coal and convert it to vapor (steam). All of that energy is typically sent out the chimney and into the atmosphere in the form of water vapor, unless a condensing boiler is used which may claim part of the escaping energy. So to get a million BTUs of useful energy from the fuel, a larger mass of wood or coal is necessary to compensate for the losses from vaporizing all that water. More wood or coal per unit of energy means more CO_2 per unit of energy.

With coal, the higher water content grades also have lower carbon content and higher content of volatiles. The net effect of this is that on average CO_2 outputs are relatively consistent across grades (see Table 2).

Table 3 below shows the CO_2 production for wood from zero to 50% MC. The Manomet study used 45% (page 103).

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[1] The peer review of our work by Daniel Parrent, Biomass and Forest Stewardship Coordinator, USDA Forest Service, Anchorage AK was invaluable.

[2] http://www.manomet.org/sites/manomet.org/files/Manomet_Biomass_Report_Full_LoRez.pdf. FutureMetrics' papers are at www.FutureMetrics.com

[3] Based on data in the table in appendix 2-A on page 129 of the study.

At 45% MC the combustion of wood yields about 9.0% more CO_2 per unit of useful energy than an average of the coal grades' outputs[4]. While still more than coal, this is significantly less than the 34.6% difference that drives the Manomet "debt-then-dividend" model. Even if we were to accept this model, this would suggest that the debts generated in their models should be paid off much sooner than the study shows.

This also illustrates how each location will have different outcomes. Coal grades, wood species, moisture contents of both coal and wood, and boiler efficiency will yield unique metrics.

While we stand behind our logic in all of our previous papers on the carbon neutrality of wood combustion (with the sustainability constraint as the essential foundation of that logic), we also have shown here that dried wood at MC's below 20% have the same or less CO_2 emission per MMBTU as most coal. Wood pellets at under 10% MC result in less CO_2 emission than any coal under otherwise equal circumstances.

Interestingly, it would appear that if a conventional low efficiency biomass power plant were to use what is otherwise waste heat from the condenser cooling loop to pre-dry the fuel as part of the fuel processing it would lower the net CO_2 output per unit of useful energy produced. The same technology may also apply to pre-treat lower grade (wetter) coal.

In conclusion, wood in a low moisture content state has lower instantaneous CO_2 emissions per unit of energy produced than coal. But of course formation of new coal to recycle the carbon released from any coal combustion takes eons. As we have clearly shown in our previous papers on this subject, with sustainable working forest management, the recycling of carbon from wood combustion is virtually instantaneous and continuous and therefore the net stock of CO_2 in the atmosphere from the combustion of wood is not increased.

[4] This assumes that both the coal plant and the biomass power plant have the same boiler efficiency. This may not be true for older stoker biomass power plants but is true for modern fluidized bed systems.

Table 1

Species	Density	Weight Per Cord	BTU's Per Cord (at 20% MC - air dryed)	BTU's per Cord (at 45% MC)	Units needed to produce 1 Million BTU's	Higher HV	Lower HV (NHV)	Units (kg)	C content (average)		CO_2 output (LHV)
	(lbs per ft^3)	(lbs)	(millions)	(millions)		MMBTUs/ton	MMBTUs/ton	1/MMBTU	Hardwood 47-50%	Softwood 50 -53%	(kg/MMBTU)
Hickory	50.9	4327	27.7	19.39	0.052	16.69	15.29	65.38	48.50%		116.27
East. Hophornbeam	50.2	4267	27.3	19.11	0.052	16.68	15.29	65.42	48.50%		116.34
Apple	48.7	4100	26.5	18.55	0.054	16.85	15.44	64.76	48.50%		115.16
White Oak	47.2	4012	25.7	17.99	0.056	16.70	15.30	65.34	48.50%		116.20
Sugar Maple	44.2	3757	24	16.8	0.06	16.65	15.26	65.52	48.50%		116.52
Red Oak	44.2	3757	24	16.8	0.06	16.65	15.26	65.52	48.50%		116.52
Beech	44.2	3757	24	16.8	0.06	16.65	15.26	65.52	48.50%		116.52
Yellow Birch	43.4	3689	23.6	16.52	0.061	16.68	15.28	65.43	48.50%		116.35
White Ash	43.4	3689	23.6	16.52	0.061	16.68	15.28	65.43	48.50%		116.35
Hackberry	38.2	3247	20.8	14.56	0.069	16.70	15.30	65.34	48.50%		116.19
Tamarack	38.2	3247	20.8	14.56	0.069	16.70	15.30	65.34	48.50%		116.19
Paper Birch	37.4	3179	20.3	14.21	0.07	16.64	15.26	65.55	48.50%		116.56
Cherry	36.7	3121	20	14	0.071	16.70	15.31	65.31	48.50%		116.15
Elm	35.9	3052	19.5	13.65	0.073	16.65	15.27	65.51	48.50%		116.50
Black Ash	35.2	2992	19.1	13.37	0.075	16.64	15.25	65.57	48.50%		116.60
Red Maple	34.4	2924	18.7	13.09	0.076	16.67	15.28	65.45	48.50%		116.39
Boxelder	32.9	2797	17.9	12.53	0.08	16.68	15.29	65.40	48.50%		116.31
Jack Pine	31.4	2669	17.1	11.97	0.084	16.70	15.31	65.33		51.50%	123.36
Norway Pine	31.4	2669	17.1	11.97	0.084	16.70	15.31	65.33		51.50%	123.36
Hemlock	29.2	2482	15.9	11.13	0.09	16.70	15.31	65.34		51.50%	123.38
Black Spruce	29.2	2482	15.9	11.13	0.09	16.70	15.31	65.34		51.50%	123.38
Ponderosa Pine	28	2380	15.2	10.64	0.094	16.65	15.26	65.54		51.50%	123.75
Aspen	27	2290	14.7	10.29	0.097	16.73	15.34	65.20		51.50%	123.12
White Pine	26.3	2236	14.3	10.01	0.1	16.67	15.28	65.45		51.50%	123.58
Balsam Fir	26.3	2236	14.3	10.01	0.1	16.67	15.28	65.45		51.50%	123.58
Cottonwood	24.8	2108	13.5	9.45	0.106	16.69	15.30	65.36		51.50%	123.41
Basswood	24.8	2108	13.5	9.45	0.106	16.69	15.30	65.36		51.50%	123.41

Table 2

Coal Grade	HHV	LHV	kg	C content range		CO_2 output
	MMBTUs/ton	MMBTUs/ton	1/MMBTU	low	high	(kg/MMBTU)
Anthracite	29.74	29.01	34.47	0.92	0.98	**120.07**
Bituminous	25.88	24.77	40.38	0.65	0.92	**115.48**
Sub-Bituminous	20.93	19.48	51.33	0.45	0.65	**122.33**
Lignite	13.55	11.69	85.56	0.25	0.45	**125.49**

Table 3

C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
MCx	ratio MCx wood to MC0 wood	DME (dry mass eq.) (kg MCx/kgMC0)	GHV (MJ/kg)	wood (kg/tonne)	water (kg/tonne)	carbon (kg/tonne)	water to evap. (kg/DME)	energy lost (MJ/DME)	energy lost (MMBtu/DME)	NHV (MJ/kg)	Efficiency including losses from the enthalpy of vaporization (%)	Usable net HV (MMBtu/DME)	DME (kg) of MCx wood per MMBtu of Usable HV	Corresponding C content (kg/MMBtu UHV)	CO2 generation (kg/MMBtu HHV)
0	1.000	1000.000	19.80	1000	0	500	0.00	0.0	0.000	16.83	85.0	15.95	62.68	31.34	114.91
5	1.053	1052.632	18.81	950	50	475	52.63	118.8	0.113	15.80	84.0	15.77	66.76	31.71	116.28
8	1.087	1086.957	18.22	920	80	460	86.96	196.3	0.186	15.21	83.5	15.67	69.35	31.90	116.97
10	1.111	1111.111	17.82	900	100	450	111.11	250.8	0.238	14.79	83.0	15.58	71.32	32.09	117.68
15	1.176	1176.471	16.83	850	150	425	176.47	398.3	0.378	13.80	82.0	15.39	76.44	32.48	119.11
20	1.250	1250.000	15.84	800	200	400	250.00	564.3	0.535	12.83	81.0	15.20	82.22	32.89	120.58
25	1.333	1333.333	14.85	750	250	375	333.33	752.3	0.713	11.88	80.0	15.02	88.79	33.30	122.09
30	1.429	1428.571	13.86	700	300	350	428.57	967.3	0.917	10.95	79.0	14.83	96.34	33.72	123.63
35	1.538	1538.462	12.87	650	350	325	538.46	1215.3	1.152	10.04	78.0	14.64	105.08	34.15	125.22
40	1.667	1666.667	11.88	600	400	300	666.67	1504.7	1.426	9.15	77.0	14.45	115.31	34.59	126.85
45	**1.818**	**1818.182**	**10.89**	**550**	**450**	**275**	**818.18**	**1846.6**	**1.751**	**8.11**	74.5	**13.98**	**130.02**	**35.76**	**131.10**
50	2.000	2000.000	9.90	500	500	250	1000.00	2257.0	2.140	7.13	72.0	13.51	147.99	37.00	135.65

Col C	MC is moisture content, wet basis. X corresponds to the stated MC
Col D	ratio MCX wood to MC0 wood is the ratio of the mass of wet material at MCx required to get 1 unit wood at MC0
Col E	DME (dry mass equivalent) is the mass of wood (kg) at MCx required to yield 1000 kg of wood at MC0
Col F	GHV (MJ/kg) is the Gross Heating Value of wood. GHV = high heating value (HHV) * (1-MC/100)
Col G	wood (kg/tonne) is the mass of bone dry wood in 1 tonne of wood at MCx
Col H	water (kg/tonne) is the mass of water in 1 tonne of wood at MCx
Col I	carbon (kg/tonne) is the mass of carbon in 1 tonne of wood at MCx. Assumes C=50% by wt.
Col J	water to evaporate (kg/DME) is the mass of water to evaporate per DME
Col K	energy lost (MJ/DME) is the heat lost to the vaporization of the water in the wood; 2257 kJ/kg
Col L	energy lost (MMBtu/DME) is the heat lost to the vaporization of the water in the wood; (MJ * 948 / 1000000 = MMBtu)
Col M	NHV (MMBtu) is equal to the Gross Heat Value at MCx * Boiler Efficiency
Col N	Typical burner efficiency (%) -- accounts for the loss from the heat of vaporization
Col O	Usable net heat value (HV) = NHV * DME *948/1000000
Col P	DME (kg) of MCx wood per MMBtu Usable HV = DME / Usable HV
Col Q	Corresponding C content = (value from Col P * carbon content from Col I) / 1000
Col R	CO2 generation = value from Col Q * 44/12

Sources for underlying data:

http://www.engineeringtoolbox.com/wood-combustion-heat-d_372.html
http://www.hearth.com/econtent/index.php/articles/heating_value_wood
http://extension.missouri.edu/explorepdf/agguides/forestry/g05450.pdf
http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf