EMISSIONS FROM BIOMASS COMBUSTION

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Presentation

- Background on Biomass
- Combustion Primer
- Major Emissions
- Minor/Trace Emissions
- Conclusions

Biomass Utilization

- Advantages
  - Lower cost
  - "Green" fuel source
  - Carbon neutral
  - Renewable waste
- Limitations
  - Energy density (1/10th that of coal!)
  - Handling/preparation issues
  - Ash sales

Background

- Biomass Types *Considered*
  - Woody
    - Sawdust, pallets, pellets, railroad ties, fiberboard, etc.
  - Herbaceous
    - Crop wastes, vineyard wastes, short-rotation crops, etc.
- Generic "Biomass" (Alternate) Fuels – *Not Considered*
  - Tire-derived fuel
  - Animal renderings
  - Poultry litter
  - Petroleum coke

Woody Biomass Major Analyses

PARAMETER	Pine	Red Oak	Sawdust	Wood Waste	Paneling	Prtcleboard	Plywood
Moisture	45.00	28.80	40.00	30.80			
Proximate (Dry)							
Volatile Matter	84.70	79.50	80.00	76.00	79.93	79.74	81.61
Ash	0.10	1.50	1.00	5.90	1.12	0.41	0.88
Fixed Carbon	15.20	19.00	19.00	18.10	18.95	19.85	17.51
Ultimate (Dry)							
Carbon	49.10	51.60	49.20	48.00	50.47	51.00	52.20
Hydrogen	6.40	5.80	6.00	5.50	5.83	6.34	6.27
Nitrogen	0.20	0.50	0.40	1.40	2.97	2.72	0.29
Sulfur	0.20	0.10	0.10	0.10	0.02	0.03	0.01
Oxygen	44.00	40.50	43.30	39.10	39.59	39.50	40.35
Chlorine	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ash	0.10	1.50	1.00	5.90	1.12	0.41	0.88
Heating Value (Dry)							
Btu/lb	8502	8069	8400	8364			

Data from Tillman and Harding, 2004

Woody Biomass Minor Analyses

	Pine	Sawdust	Pine Bark	Mixed	RR Ties	Poplar	Willow	Green Sawdust
Ash Composition (wt% of Ash)								
SiO_2	57.2	23.7	0.4	23.5	47.3	59.2	4.4	21.3
Al_2O_3	13.4	4.1	0.3	5.1	16.8	16.7	1.5	4.6
TiO_2	1.2	0.4	0.0	0.1	1.3	0.7	1.4	0.6
Fe_2O_3	5.9	1.7	0.2	2.1	12.3	8.2	1.0	2.0
CaO	8.8	39.9	40.6	33.6	9.2	4.9	54.1	39.8
MgO	3.4	4.8	5.1	5.1	4.2	2.1	4.2	6.6
Na_2O	1.4	2.3	0.3	0.2	2.7	0.3	0.8	2.2
K_2O	4.9	9.8	26.5	12.0	2.2	8.1	12.5	9.5
P_2O_5	1.4	2.1	11.5	4.8	0.6	0.6	1.4	3.0
SO_3	0.1	1.9	3.0	1.6	0.7	0.1	3.6	1.9

Data from Tillman and Harding, 2004

Woody Biomass Trace Analyses

	Big Valley Lumber	Bulington Electric	Georgia Pacific	Hog Fuel
Element (ppm)				
As	4.6	6.3		0.475
Ba	130	--	--	51.5
Be	0.1	--	--	BDL
Cd	1.5	16	6.7	BDL
Cr	22	25	16.8	128.4
Cu	40	70	49.2	5.625
Pb	38	70	76.9	2.71
Hg	<0.05	--	58.8	BDL
Mo	14	3	--	--
Ni	11	--	--	137.3
Se	5	--	--	--
Ag	<0.08	--	--	--
V	26	27	--	--
Zn	130	560	310	99

Data from Tillman and Harding, 2004

Herbaceous Biomass Major Analyses

PARAMETER	Fresh Switchgrass	Weathered Switchgrass	Reed Canary Grass	Mulch Hay	Cotton Gin Trash	Rice Hulls	Vineyard Prunings	Hybrid Seed Corn
Moisture	15	15	65.2	19.5	7-12	7-10	20-40	12
Proximate (Dry)								
Volatile Matter	76.18	81.8	76.1	77.6	75.4	63.6	74.9	78.32
Ash	7.74	3.4	4.1	5.3	9.2	20.6	10.8	1.53
Fixed Carbon	16.08	14.8	19.8	17.1	15.4	15.8	14.3	20.15
Ultimate (Dry)								
Carbon	46.73	49.4	45.8	46.5	42.77	38.3	47.99	46
Hydrogen	5.88	5.9	6.1	5.7	5.08	4.36	5.65	6.13
Nitrogen	0.54	0.4	1	1.7	1.53	0.83	0.86	1.84
Sulfur	0.13	0.3	0.1	0.2	0.55	0.06	0.08	0.18
Oxygen	38.98	40.6	42.9	40.6	40.87	35.85	39.61	44.32
Ash	7.74	3.4	4.1	5.3	9.2	20.6	5.81	1.53
Heating Value (Dry)								
Btu/lb	7750	8150	7103	8058	6700	6400	7220	8222

Data from Tillman and Harding, 2004

Herbaceous Biomass Minor Analyses

	Fresh Switchgrass	Weathered Switchgrass	Alfalfa Stems	Wheat Straw	Rice Straw
Ash Composition (wt% of Ash)					
SiO_2	65.2	65.4	1.4	55.7	73.0
Al_2O_3	4.5	7.0	0.6	1.8	1.4
TiO_2	0.2	0.3	0.1	0.0	0.0
Fe_2O_3	2.0	3.6	0.3	0.7	0.6
CaO	5.6	7.1	12.9	2.6	1.9
MgO	3.0	3.2	4.2	2.4	1.8
Na_2O	0.6	1.0	0.6	0.9	0.4
K_2O	11.6	7.0	40.5	22.8	13.5
P_2O_5	4.5	2.8	7.7	1.2	1.4
SO_3	0.4	2.0	1.6	1.7	0.7
CO_2	0.0	0.0	17.4	0.0	0.0

Data from Tillman and Harding, 2004

Herbaceous Biomass Trace Analyses

	Agricultural Material	
	Minimum	Maximum
Element (ppm)		
Sb	10	10
As	3.4	12
Ba	41	220
Be	0.01	0.06
Cd	0.36	1.1
Cr	11	20
Co	2.9	14
Cu	14	31
Pb	21	55
Hg	BDL	BDL
Ni	4.4	5.8
Se	BDL	BDL
V	11	20
Zn	40	190

Data from Tillman and Harding, 2004

Combustion Primer

- General combustion reaction

$$C_aH_b + (a+b/4)O_2 \rightarrow aCO_2 + (b/2)H_2O + heat$$

- All hydrocarbon fuels have additional species

$$C_aH_bS_cN_dO_e + (a+c+b/4+0.15d-e/2)O_2 \rightarrow heat + aCO_2 + cSO_2 + 0.3dNO + 0.35dN_2 + (b/2)H_2O$$

- Never achieve 100% efficiency

$$C_aH_bS_cN_dO_e + (1.03a+1.03c+0.26b+0.18d-e/2)O_2 \rightarrow aCO_2 + cSO_2 + 0.3dNO + 0.35dN_2 + (b/2)H_2O + 0.03(a+c+0.65d+b/2)O_2 + a/1000CO + heat$$

Combustion Primer (Con't.)

- Finally, air not oxygen is used as oxidizer

$$C_aH_bS_cN_dO_e + (1.03a+1.03c+0.26b+0.18d-e/2)O_2 + 3.76(1.03a+1.03c+0.26b+0.18d-e/2)N_2 \rightarrow aCO_2 + cSO_2 + 0.4dNO + (b/2)H_2O + 0.03(a+c+0.65d+b/2)O_2 + a/1000CO + 3.76(1.03a+1.03c+0.26b+0.09d-e/2)N_2 + heat$$

- And this is only for major species in all biomass fuels!

Combustion Applications

- Dedicated facilities
  - Small scale
    - Wood burning stoves
    - Fireplaces
    - Pellet stoves
  - Large scale
    - Cyclone boilers
    - Fluidized bed boilers
    - Stoker/Grate boilers
    - Wood fuel boilers

Combustion Applications (Con't.)

- Cofiring Applications
  - Cement kilns
  - PC boilers
  - Cyclone boilers
  - Fluidized bed boilers
  - Stoker/grate boilers
  - Industrial

Major Emissions - General

- Particulates
  - Function of ash concentration in fuel and firing method (typically stokers/cyclones have 70-80% of ash retained on grate or bottom ash; suspension-fired units have 70-80% of ash as flyash)
- SO_2
  - Function of sulfur content in fuel; typically very low for all biomass fuels
- NO_x
  - Typically a function of fuel nitrogen and temperature; low for woody biomass but can be very high for some herbaceous crops and fecal matter (e.g., chicken manure)

Major Emissions – Large Furnaces

	Emissions (mg/MJ)			
	CO	**UHC**	**Particles**	**NO_x**
Cyclone Furnaces	338	n.m.	59	333
Fluidized Bed Boilers	0	1	2	170
PC Boilers	164	8	86	69
Grates	1846	67	122	111
Stokers	457	4	59	98
Wood Boilers	4,975	1330	n.m.	101

n.m. - not measured

Source: Van Loo & Koppejan, 2002

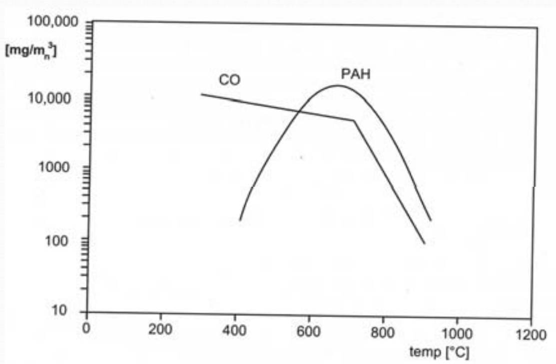
Major Emissions – Small Furnaces

	Emissions (mg/MJ)			
	CO	UHC	Particles	NO_x
Modern Wood Stove	1730	200	98	58
Traditional Wood Stove	6956	1750	1921	29
Fireplace Inserts	1164	130	18	41
Heat-storing Stoves	965	92	19	51
Pellet Stoves	110	3	11	36
	Source: Van Loo & Koppejan, 2002			

Minor Emissions – Large Furnaces

	Emissions (mg/MJ)		
	Tar	VOC	PAH*
Cyclone Furnaces	n.m.	2.1	n.m.
Fluidized Bed Boilers	n.m.	n.m.	4
PC Boilers	n.m.	n.m.	22
Grates	n.m.	n.m.	4040
Stokers	n.m.	n.m.	9
Wood Boilers	499	n.m.	30
*µg/MJ	n.m. - not measured		
Data from Skreiberg and Saanum, 1994			

Effect of Temperature



Major Emissions – Wood-fired Systems

	Emission (mg/MJ)	Number of Observations
CO	44 - 700	25
UHC	1.8 - 4.4	25
NO_x	57 - 118	22
Particulates	13 - 109	29
SO_2	7 - 26	17
Source: Van Loo & Koppejan, 2002		

Minor Emissions – Wood-fired Systems

	Emission (mg/MJ)	Number of Observations
PAH	2.1E^{-4} - 2.1E^{-2}	unknown
Benzopyrene	1.75E^{-5} - 3.5E^{-4}	4
Cl	3.5	12
F	8.8E^{-2} -	unknown
Dioxin/Furan*	5.32E^{-7} - 6.41E^{-6}	*
Source: Van Loo & Koppejan, 2002		
* Hog fuel, *Source: Tillman, 2009*		

Comparison of Selected Emissions as a Function of Biomass Fuel

Emission (at 11% O2, dry basis	Biomass Fuel Type	Range (mg/MJ)
NO_x	Native wood	35 - 88
	Straw, grass, herbaceous	105 - 280
	Urban wood waste	140 - 210
HCl	Native wood	<2
	Straw, grass, herbaceous	35 - 350
	Urban wood waste	35 - 350
Particulate (after cyclone)	Native wood	17 - 53
	Straw, grass, herbaceous	53 - 350
	Urban wood waste	NA

Source: van Loo and Koppejan, 2002

Conclusions

- Biomass-fired boilers have emissions that vary as a function of
  - Type of boiler
  - Firing conditions
  - Type of biomass fuel
- Large-scale biomass-fired boilers emit less than wood-fired stoves, fireplaces, and other residential systems
- Biomass-fired boilers can emit more or less than coal-fired boilers depending upon fuel characteristics and post-combustion controls