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CHARACTERISTICS OF BIOMASS COMBUSTION EMISSIONS

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OUTLINE

- BIOMASS BASICS
- COMBUSTION PRIMER
- MAJOR EMISSIONS
- MINOR/TRACE EMISSIONS
- EMISSION CONTROL BASICS
- CONCLUSIONS

BACKGROUND

- TYPES OF BIOMASS CONSIDERED
  - WOODY
    - SAWDUST, PELLETS, RAILROAD TIES, FIBERBOARD, OTHERS
  - HERBACEOUS
    - CROP WASTES, VINEYARD WASTES, SHORT ROTATION CROPS, OTHERS
  - DEFINITION OF BIOMASS IS BOTH COUNTRY AND STATE DEPENDENT
- OTHER BIOMASS FUELS NOT CONSIDERED HERE
  - ANIMAL RENDERINGS
  - POULTRY LITTER
  - SWINE MANURE, COW AND STEER MANURE

USES OF BIOMASS IN ENERGY GENERATION

- ADVANTAGES
  - "GREEN" ENERGY SOURCE
  - CARBON NEUTRAL
  - RENEWABLE WASTE
  - VERY LOW SULFUR
  - WOODY MATERIALS ARE LOW IN CHLORINE AND ASH CONTENT
- DISADVANTAGES
  - HIGH MOISTURE, PARTIALLY OXIDIZED MATERIAL LEADING TO LOWER THERMAL EFFICIENCY
  - LOW ENERGY DENSITY [BTU/CU FT]
  - HANDLING/PREPARATION ISSUES
  - SALABILITY OF ASH IS VERY LIMITED
  - REACTIVE ALKALI METALS IN THE ASH

WOODY BIOMASS REPRESENTATIVE ANALYSES COMPARED TO TYPICAL COAL

PARAMETER	SAWDUST	URBAN WOOD WASTE	PITTSBURGH SEAM BITUMINOUS COAL
MOISTURE	40.00	30.80	11.00
PROXIMATE ANALYSIS (% DRY WEIGHT)			
FIXED CARBON	19.00	18.10	55.70
VOLATILE MATTER	80.00	76.00	30.60
ASH	1.00	5.90	13.70
ULTIMATE ANALYSIS (% DRY WEIGHT)			
CARBON	49.20	48.00	73.60
HYDROGEN	6.00	5.50	4.70
OXYGEN	43.30	39.10	5.10
NITROGEN	0.40	1.40	1.30
SULFUR	0.10	0.10	1.60
ASH	1.00	5.90	13.70
HIGHER HEATING VALUE (BTU/LB, DRY BASIS)	8,400	8,364	13,000
CHLORINE (ppm whole fuel, dry)	-	-	400

Source: Tillman and Harding, 2004; Miller and Tillman, 2008

WOODY BIOMASS ASH MINERAL ANALYSIS COMPARED TO TYPICAL COAL

Ash Mineral Analysis (% Weight of Ash)			
PARAMETERS	Sawdust	Mixed Wood	Pittsburgh Seam Bituminous Coal
SiO_2	23.70	23.50	55.80
Al_2O_3	4.10	5.10	25.80
TiO_2	0.40	0.10	1.21
Fe_2O_3	1.70	2.10	6.37
CaO	39.90	33.60	3.20
MgO	4.80	5.10	0.91
Na_2O	2.30	0.20	0.49
K_2O	9.80	12.00	2.19
P_2O_5	2.10	4.80	0.56
SO_3	1.90	1.60	2.10

Source: Tillman and Harding, 2004; Miller and Tillman, 2008

WOODY BIOMASS TRACE METAL ANALYSIS COMPARED TO TYPICAL COAL

TRACE ELEMENTS (PPM)			
PARAMETERS	HOG FUEL	URBAN WOOD WASTE	PITTSBURGH SEAM BITUMINOUS COAL
Arsenic (As)	0.475	2.145	5.94 – 12.23
Chromium (Cr)	128.4	6.57	16.8 -29.6
Lead (Pb)	2.71	2.922	3.7 – 6.23
Mercury (Hg)	Below Detection Limit	0.0126	0.11 - 0.18
Nickel (Ni)	137.3	2.645	8.7 – 14.1
Vanadium (V)	--	3.060	7

Source: Tillman and Harding, 2004; Miller and Tillman, 2008

HERBACEOUS BIOMASS REPRESENTATIVE ANALYSES COMPARED TO TYPICAL COAL

PARAMETER	FRESH SWITCHGRASS	WEATHERED SWITCHGRASS	RICE HULLS	PITTSBURGH SEAM BITUMINOUS COAL
MOISTURE	15	15	7 – 10	11.00
PROXIMATE ANALYSIS (% DRY WEIGHT)				
FIXED CARBON	16.08	14.80	15.80	55.70
VOLATILE MATTER	76.18	81.8	63.60	30.60
ASH	7.74	3.40	20.60	13.70
ULTIMATE ANALYSIS (% DRY WEIGHT)				
CARBON	46.73	49.40	38.30	73.60
HYDROGEN	5.88	5.90	4.36	4.70
OXYGEN	38.98	40.60	35.85	5.10
NITROGEN	0.54	0.40	0.83	1.30
SULFUR	0.13	0.30	0.06	1.60
ASH	7.74	3.40	20.60	13.70
HIGHER HEATING VALUE (BTU/LB, DRY BASIS)	7,750	8,150	6,400	13,000
CHLORINE (ppm whole fuel, dry)	800 - 1600	800 - 1600	5000	400

Source: Tillman and Harding, 2004; Miller and Tillman, 2008

HERBACEOUS BIOMASS ASH MINERAL ANALYSIS COMPARED TO TYPICAL COAL

Ash Mineral Analysis (% Weight of Ash)				
PARAMETERS	FRESH SWITCHGRASS	WEATHERED SWITCHGRASS	RICE STRAWS	Pittsburgh Seam Bituminous Coal
SiO_2	65.20	65.40	73.00	55.80
Al_2O_3	4.50	7.00	1.40	25.80
TiO_2	0.20	0.30	0.00	1.21
Fe_2O_3	2.00	3.60	0.60	6.37
CaO	5.60	7.10	1.90	3.20
MgO	3.00	3.20	1.80	0.91
Na_2O	0.60	1.00	0.40	0.49
K_2O	11.60	7.00	13.50	2.19
P_2O_5	4.50	2.80	1.40	0.56
SO_3	0.40	2.00	0.70	2.10

Source: Tillman and Harding, 2004; Miller and Tillman, 2008

HERBACEOUS BIOMASS TRACE METAL ANALYSIS COMPARED TO TYPICAL COAL

TRACE ELEMENTS (PPM)			
PARAMETERS	AGRICULTURAL MATERIAL		PITTSBURGH SEAM BITUMINOUS COAL
	MINIMUM	MAXIMUM	
Arsenic (As)	3.4	12	5.94 – 12.23
Chromium (Cr)	11	20	16.8 -29.6
Lead (Pb)	21	55	3.7 – 6.23
Mercury (Hg)	Below Detection Limit	Below Detection Limit	0.11 - 0.18
Nickel (Ni)	4.4	5.8	8.7 – 14.1
Vanadium (V)	11	20	7

Sources: DeVito, Rosendale, and Conrad, 1993; Tillman, 1994; Tillman and Harding, 2004; Miller and Tillman, 2008

BASICS OF COMBUSTION

- General combustion reaction

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

- Hydrocarbon fuels have additional species

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

- Can never achieve 100% efficiency

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

BASICS OF COMBUSTION CONTINUED

- Air, not oxygen is the 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 → 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

APPLICATIONS OF BIOMASS COMBUSTION

- SMALL SCALE
  - WOOD BURNING STOVES
  - FIREPLACES
  - PELLET STOVES
- LARGE SCALE
  - FLUIDIZED BED BOILERS
  - STOKER/GRATE BOILERS
  - PULVERIZED COAL BOILERS

APPLICATIONS OF BIOMASS COFIRING WITH OTHER FUELS

- CEMENT KILNS
- PULVERIZED COAL BOILERS
- CYCLONE BOILERS
- FLUIDIZED BED BOILERS
- STOKER/GRATE BOILERS
- APPLICATIONS
  - ELECTRICITY GENERATION
  - INDUSTRIAL [STEAM/HOT WATER] BOILERS AND DIRECT HEAT PROCESSES

MAJOR EMISSION CONSTITUENTS

- PARTICULATES
  - DEPENDENT ON ASH CONCENTRATION IN FUEL AND METHOD OF FIRING
- SO_2
  - FUNCTION OF FUEL SULFUR CONCENTRATION
  - MOST BIOMASS FUELS HAVE INHERENTLY LOW SULFUR CONTENT
- NO_X
  - FUNCTION OF BOTH FUEL NITROGEN AND TEMPERATURE
  - WOODY BIOMASS ARE LOW IN FUEL NITROGEN CONTENT
  - FUEL NITROGEN CAN BE HIGH IN SOME HERBACEOUS CROPS AND FECAL MATTER
  - LOWER COMBUSTION TEMPERATURES [THAN FOSSIL FUELS]

EMISSIONS FROM WOOD-FIRED COMBUSTION SYSTEMS

Combustor type	NOx mg/MJ	Particlates mg/MJ	CO mg/MJ	UHC (as CH4) mg/MJ	PAH mg/MJ
Fluid bed	64	2	0	1	4
Suspension burner	69	86	164	8	22
Stoker boiler	98	59	457	4	9
Modern wood stove	58	98	1730	200	26
Traditional wood stove	29	1921	6956	1750	3445

*** SI Units**

Source: Sjaak van Loo and Jaap Koppejan (eds). 2002. Biomass: Combustion and Cofiring. Twente University Press, the Netherlands

EMISSIONS FROM WOOD-FIRED COMBUSTION SYSTEMS

Combustor type	NOx Lb/10^6 Btu	Particulates Lb/10^6 Btu	CO Lb/10^6 Btu	UHC (as CH_4) Lb/10^6 Btu	PAH Lb/10^6 Btu
Fluid bed	0.150	0.00465	0	0.00233	0.00931
Suspension burner	0.161	0.200	0.381	0.0186	0.0512
Stoker boiler	0.228	0.137	1.063	0.0093	0.021
Modern wood stove	0.135	0.228	4.024	0.465	0.0601
Traditional wood stove	0.0675	4.468	16.180	4.071	8.013

*** English Units**

Source: Sjaak van Loo and Jaap Koppejan (eds). 2002. Biomass: Combustion and Cofiring. Twente University Press, the Netherlands

SELECTED EMISSIONS AS A FUNCTION OF BIOMASS FUEL

Emission (at 11% O_2, dry basis)	Biomass Fuel Type	Range (mg/m^3)
NOx	Native wood	100 – 250
	Straw, grass, herbaceous	300 – 800
	Urban wood waste	400 – 600
HCl	Native wood	<5
	Straw, grass, herbaceous	100 – 1000
	Urban wood waste	100 – 1000
Particulate (after cyclone)	Native wood	50 – 150
	Straw, grass, herbaceous	150 - 1000
	Urban wood waste	NA

*** SI Units**

Source: Sjaak van Loo and Jaap Koppejan (eds). 2002. Biomass: Combustion and Cofiring. Twente University Press, the Netherlands

SELECTED EMISSIONS AS A FUNCTION OF BIOMASS FUEL

Emission (at 11% O_2, dry basis)	Biomass Fuel Type	Range
Nox [lb/10^6 Btu]	Native wood	0.0577 – 0.144
	Straw, grass, herbaceous	0.173 – 0.461
	Urban wood waste	0.2307 – 0.346
HCl [lb/10^6 Btu]	Native wood	<0.0288
	Straw, grass, herbaceous	0.0577 – 0.577
	Urban wood waste	0.0577 – 0.577
Particulate (after cyclone) [grains/scf]	Native wood	0.0218 – 0.0655
	Straw, grass, herbaceous	0.0655 – 0.437
	Urban wood waste	NA

*** English Units; Based on F-Factor of 9240 dscf/10^6 Btu**

Source: Sjaak van Loo and Jaap Koppejan (eds). 2002. Biomass: Combustion and Cofiring. Twente University Press, the Netherlands

DIOXIN AND FURAN EMISSIONS FROM A WOOD-FIRED BOILER

Measure of concentration (in 2,3,7,8 TCDD Eq)	Result firing hog fuel
ng/m^3	1.52E-3 - 1.83E-2
Parts per trillion	6.1E-5 - 7.28E-4
lb/million Btu	1.46E-12 - 1.88E-11

"HOG FUEL" ARE WOOD TYPICALLY WOOD WASTE FROM SAWMILLS, PLYWOOD MILLS, ETC. WITH VARYING PARTICLE SIZES AND AROUND 40% H_2O.

DIOXINS AND FURANS ARE A FUNCTION OF RESIDENCE TIME AND TEMPERATURE.

Source: test files of David A. Tillman

MAJOR EMISSIONS – LARGE FURNACES

	EMISSIONS (mg/m^3)			
	CO	UHC	Particulates	NO_x
CYCLONE FURNACES	109	N.M.	169	951
FLUIDIZED BED BOILERS	0	3	6	260
PC BOILERS	469	23	246	197
GRATES	5,274	191	349	317
STOKERS	1,306	11	169	280
WOOD BOILERS	14,214	3,800	N.M.	289

*** SI Units**

N.M. – NOT MEASURED

SOURCE: SKREIBERG AND SAANUM, 1994

MAJOR EMISSIONS – LARGE FURNACES

	EMISSIONS			
	CO (lb/10^6 Btu)	UHC (lb/10^6 Btu)	Particulates (grains/scf)	NO_x (lb/10^6 Btu)
CYCLONE FURNACES	0.0629	N.M.	0.0739	0.5486
FLUIDIZED BED BOILERS	0	0.00173	0.00262	0.150
PC BOILERS	0.2705	0.0133	0.108	0.114
GRATES	3.042	0.1104	0.153	0.1829
STOKERS	0.753	0.00635	0.0739	0.162
WOOD BOILERS	8.200	2.192	N.M.	0.167

*** English Units; Based on F-Factor of 9240 dscf/10^6 Btu**

N.M. – NOT MEASURED

SOURCE: SKREIBERG AND SAANUM, 1994

MAJOR EMISSIONS – SMALL FURNACES

	EMISSIONS (mg/m^3)			
	CO	UHC	Particulates	NO_x
WOOD STOVES	4,968	581	130	118
FIREPLACE INSERTS	3,326	373	50	118
HEAT-STORING STOVES	2,756	264	54	147
PELLET STOVES	313	8	32	104

*** SI Units**

SOURCE: STREHLER, 1994

MAJOR EMISSIONS – SMALL FURNACES

	EMISSIONS (mg/m^3)			
	CO ($lb/10^6$ Btu)	UHC ($lb/10^6$ Btu)	Particulates (grains/scf)	NO_x ($lb/10^6$ Btu)
WOOD STOVES	2.864	0.335	0.0568	0.0681
FIREPLACE INSERTS	1.918	0.215	0.0218	0.0681
HEAT-STORING STOVES	1.590	0.152	0.0236	0.0848
PELLET STOVES	0.181	0.00461	0.0140	0.0600

*** English Units; Based on F-Factor of 9240 $dscf/10^6$ Btu**

SOURCE: STREHLER, 1994

MAJOR EMISSIONS – WOOD-FIRED SYSTEMS

	EMISSION (mg/m^3)	Number of Observations
CO	125 – 2000	25
UHC	5.0 – 12.5	25
NO_x	162 – 337	22
Particulates	37 – 312	29
SO_2	19 - 75	17

*** SI Units**

Source: Obernberge, 1997

MAJOR EMISSIONS – WOOD-FIRED SYSTEMS

	EMISSION	Number of Observations
CO ($lb/10^6$ Btu)	0.0721 – 1.154	25
UHC ($lb/10^6$ Btu)	0.00288 – 0.00721	25
NO_x ($lb/10^6$ Btu)	0.0934 – 0.195	22
Particulates (grains/scf)	0.0162 – 0.136	29
SO_2 ($lb/10^6$ Btu)	0.011 – 0.0433	17

*** English Units; Based on F-Factor of 9240 dscf/10^6 Btu**

Source: Obernberge, 1997

MINOR EMISSIONS – WOOD-FIRED SYSTEMS

	EMISSION (mg/m^3)	Number of Observations
PAH	0.0006 – 0.06	UNKNOWN
BENZOPYRENE	0.000005 – 0.001	4
Cl	10	12
F	0.25	UNKNOWN

*** SI Units**

Source: Obernberge, 1997

POST-COMBUSTION EMISSIONS CONTROL BASICS

- CONTROL TECHNOLOGIES AVAILABLE TO ADDRESS:
  - PARTICULATE MATTER
  - NO_X
  - SULFUR DIOXIDE
  - MERCURY
  - CARBON DIOXIDE

PARTICULATE MATTER CAPTURE

- PARTICULATE MATTER IN THE U.S. HAS DECREASED SIGNIFICANTLY SINCE THE 1970 CLEAN AIR ACT AMENDMENTS
- AVAILABLE TECHNOLOGIES
  - ELECTROSTATIC PRECIPITATORS (ESP)
  - FABRIC FILTERS / BAGHOUSES
  - MECHANICAL COLLECTORS (CYCLONES AND MULTI-CLONES)
  - WET PARTICULATE SCRUBBERS
  - HOT-GAS PARTICULATE FILTERS [CERAMIC CANDLE FILTER]
- ESP AND FABRIC FILTERS ARE THE TECHNOLOGIES OF CHOICE, COUPLED WITH MECHANICAL COLLECTORS

NO_X CONTROL

- CONVENTIONALLY, LOW NO_X BURNERS, STAGED COMBUSTION, AND GAS RECIRCULATION OR REBURN ARE USED TO REDUCE NO_X CONCENTRATIONS
- OTHER REMOVAL METHODS EMPLOYED
  - SELECTIVE NON-CATALYTIC REDUCTION (SNCR)
  - SELECTIVE CATALYTIC REDUCTION (SCR)
    - MORE EMPHASIS HAS BEEN PLACED ON SCR INSTALLATIONS DUE TO THE MORE STRINGENT EMISSION REGULATIONS
    - TO DATE COFIRING HAS NOT BEEN APPLIED AT A BOILER EQUIPPED WITH SCR TECHNOLOGY DUE TO THE POTENTIAL FOR CATALYST BLINDING AND POISONING

SULFUR DIOXIDE CONTROL

- FLUE GAS DESULFURIZATION SYSTEMS AVAILABLE
  - WET SCRUBBER TECHNOLOGY
  - SPRAY DRYER ABSORBERS (OR SEMI-DRY SYSTEMS)
  - DRY INJECTION SYSTEMS

- MANY UTILITIES UTILIZE LOWER SULFUR FUELS IN ORDER TO AVOID THE INSTALLATION OF MORE EXPENSIVE SCRUBBER TECHNOLOGIES
- BIOMASS COMBUSTION IS LOW SULFUR SO TYPICALLY THERE IS NO NEED FOR SCRUBBERS HOWEVER THE NEED MAY EXIST WHEN BURNING FECAL MATTER

MERCURY CONTROL

- MANY ORGANIZATIONS ARE IN THE PROCESS OF IDENTIFYING, DEVELOPING, AND DEMONSTRATING COST-EFFECTIVE MERCURY CONTROL TECHNOLOGIES
- CURRENT APPROACHES OF CONTROL ARE:
  - COAL TREATMENT/COMBUSTION MODIFICATIONS
  - SORBENT INJECTION [E.G., ACTIVATED CARBON WITH HALOGENATION]
  - FGD ENHANCEMENT/OXIDATION
- USE OF ACTIVATED CARBON INJECTION (ACI) HAS SHOWN THE MOST PROMISE AS A NEAR-TERM STRATEGY
- MERCURY CAPTURE FOR THE VARIOUS APCDs VARY BASED ON COAL PROPERTIES, FLY ASH PROPERTIES, APCD CONFIGURATIONS, ETC.

CARBON DIOXIDE CONTROL

- THREE KEY TECHNOLOGIES FOR CAPTURING FOSSIL CO_2 FROM COAL-FIRED POWER PLANTS
  - OXYFUEL COMBUSTION
  - PRE-COMBUSTION – INTEGRATED GASIFICATION COMBINED CYCLE (IGCC)
  - POST COMBUSTION CO_2 SCRUBBING
- MANY OF THESE TECHNOLOGIES HAVE HIGH ECONOMIC COST AND SIGNIFICANT ENERGY PENALTIES ASSOCIATED
- *BIOMASS IS CONSIDERED CARBON NEUTRAL AND IS FREQUENTLY PROPOSED AS A FOSSIL CO_2 REDUCTION STRATEGY*

CONCLUSIONS

- EMISSIONS FROM BIOMASS FIRED BOILERS VARY AS A FUNCTION OF
  - BOILER TYPE
  - FIRING CONDITIONS
  - TYPE OF BIOMASS FUEL
- LARGE-SCALED BIOMASS-FIRED BOILERS CONTRIBUTE LESS EMISSIONS THAN SMALL-SCALED APPLICATIONS (WOOD-FIRED STOVES, FIREPLACES, ETC.)
- BIOMASS-FIRED BOILERS CAN HAVE MORE OR LESS EMISSIONIS THAN COAL-FIRED BOILERS; THIS DEPENDS ON FUEL CHARACTERISTICS AND POST-COMBUSTION CONTROL TECHNOLOGIES APPLIED
- POST-COMBUSTION CONTROL TECHNOLOGY APPLIED DEPENDS ON MANY FACTORS (COST, BOILER TYPE, OTHERS) AND EMISSION REGULATIONS