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Combustion-Fuel Properties of Manure or Compost from Paved vs. Un-paved Cattle Feedlots

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Abstract. Research was conducted to determine the effects of feedlot surfacing materials (soil vs. coal-ash paved) and partial composting on feedlot biomass (FB) characteristics for use in thermochemical energy conversion involving reburn or co-firing with coal or lignite. FB was harvested from 12 fly ash-paved pens and 6 soil-surfaced pens and was windrow-composted. Higher heating value (HHV) before composting was more than twice as high for manure from paved (LA-FB) vs. soil-surfaced (HA-FB) pens, and ash content dry matter basis was 66% lower for FB from paved (20.2%) vs. un-paved pens (58.7%). Partial composting (51-55 days) reduced HHV by 2-20% to 5,704 BTU/lb (at 19.6% moisture) and 2,230 BTU/lb (at 17.0% moisture) for low-ash (LA-FB-PC)/paved pens and high-ash (HA-FB-PC)/un-paved pens, respectively.

Keywords. Renewable energy, livestock waste, manure, beef cattle, biomass, air quality.

Introduction

The Texas High Plains is at the center of the "cattle feeding capitol of the world", with 42% of the U. S. fed beef production within a 200 mile radius of Amarillo TX, including neighboring states of OK, NM, KS and CO. Environmental quality and natural resource challenges facing the livestock feeding industry in the Southern Great Plains include: declining groundwater supplies in the Ogallala Aquifer, air quality emissions, particulate matter, odor, ammonia, hydrogen sulfide, volatile organic compounds, water quality protection, nutrient/soil management, mortality disposal, and energy cost-efficiency. New manure management approaches are becoming necessary for a sustainable beef cattle feeding industry in this region. While the cattle-feeding industry has been a national leader in supporting technology development and adoption to comply with increasingly stringent federal and state CAFO regulations, innovative technology and multi- environmental media approaches to manure management that conjunctively address water and air quality, soil quality, energy, climate change, and biomass energy utilization likely will be needed to meet future policies (Auvermann & Sweeten, 2005). Continued robust growth of the High Plains cattle-feeding industry is made possible by rising grain imports from other states, which now exceed 50%, according to industry estimates. With declining irrigated acres and applied nutrient amounts per acre, together with tradeoffs to lower water-use and less nutrient-intensive crops (Greene and Vasconcelos, 2005), longer hauling distances will be needed to accommodate phosphorus limitations on manure/wastewater application. Alternative utilization strategies for feedlot manure including use as an energy feedstock may become increasingly attractive for sustainable and efficient manure utilization within the cattle-feeding industry.

Particulate matter (PM) emissions, i.e. feedyard dust, may result in complaints, typically regulated at the state or local level in addition to involving National Ambient Air Quality Standards for PM10 and PM2.5 (Sweeten at al., 2000). Technologies that will control feedlot PM to manageable levels are being developed under a CSREES-funded project (Sweeten et al. 2005), which includes gaining a fundamental understanding of the physical/biological mechanisms that produce feedlot dust (Razote et al. 2005), together with a Feedyard Air Quality Management Program (FAQMP), as a management tool to enable producers to reduce dust emissions (Auvermann, 2005).

Energy use at cattle feeding operations is substantial (Sweeten, 1996), and costs continue to escalate. Potential exists for on-site production & utilization of renewable energy including biomass conversion (Annamalai et al. 2005 b). Renewable energy options involving animal wastes include: (a) methane capture from anaerobic waste storage/treatment units, and (b) thermochemical conversion using pyrolysis, combustion (including co-firing with coal or lignite) (Arumugam et al. 2005-b), gasification (Priyadarsan et al. 2004 & 2005), or reburn processes (Arumugam et al. 2005-a; Annamalai et al. 2005a). Thermochemical conversion greatly reduces the volume of volatile materials, with residue (ash) material containing noncombustible minerals including N, K, P, and Cl which could be transported greater distances than bulk manure, if these materials can be utilized beneficially. Thermochemical conversion may provide a means of utilizing composted carcasses that could result from normal mortalities or major disease outbreaks on a local or regional scale. Several large, commercial feedyards have successfully incorporated carcass composting with feedlot manure (Auvermann & Sweeten 2005).

The Texas A&M University System is contributing major efforts to determine the effects of feedlot and open-lot dairy manure management practices on manure characteristics for use in biomass energy conversion systems involving reburn or co-firing with coal or lignite as base fuel. A research program focus is being placed on maximizing higher heating value (HHV), minimizing ash content, and/or minimizing mineral contaminants (S, Cl, Na, K, P, etc) that can contribute to ash agglomeration or slagging in combustion units (Sweeten et al. 2003). Current attention is being placed on (a) reburn technology to reduce nitrogen oxide (NO_x) (Annamalai and Sweeten, 2005) and heavy metals (e.g. mercury, Hg) emissions); (b) utilization of ensuing combustion ash as potential construction or fertilization material (Megel et al., 2006), and (c) preparing, characterizing, and supplying manure from the TAES/ARS experimental feedlot at Bushland, or from commercial feedlots, to specification for use in combustion, gasification, and/or reburn experiments to be conducted in a 29.3 kW (100,000 BTU/hr) pilot facility in the TAMU Mechanical Engineering Department (MENG)/Renewable Energy Laboratory, Texas Engineering Experiment Station (TEES) (Annamalai et al. 2003). The experimental biomass materials include cattle feedlot manure produced from experimental cattle rations (Heflin et al., 2002) and from alternative surfacing materials (paved or unpaved feed pens). Experimental materials are either un-composted or partially composted (30-60 days) to improve chemical and physical uniformity, followed by solar drying and particle size reduction (e.g. 50% passing a 70 µm sieve) to accommodate co-firing or reburn experiments.

FB can be important reburn fuel due to its volatile matter, reactive N as urea and NH4 content which reacts with NOx (Annamalai et al. 2005a). Reburn tests have showed greater NOx emissions reduction using pulverized partially-composted FB than baseline coal as reburn fuel.

Objectives

The purpose of this research program is to evaluate feedlot biomass as a renewable energy resource for thermochemical processes. Specific objectives were as follows:

1) Characterize harvested cattle feedlot manure from paved vs. un-paved feedpens as a biomass energy feedstock for combustion, gasification, reburn, or pyrolyis pilot plant test burns.
2) Determine difference in harvested feedlot manure biomass chemical control or heating value as a function of feedlot surfacing materials and partial composting.

Materials and Methods

Feedlot Biomass Harvesting and Preparation

The cattle feedlot manure/biomass (FB) reported on in this study resulted from a 135-day beef cattle feeding trial at the TAES/ARS experimental feedyard in Bushland, TX, which concluded in May 2005. The feeding trial used cattle rations containing trace amounts of a commercial bicarbonate acid buffer supplement (0.0 to 0.5 % weight basis). When the feeding trial was terminated, manure (FB) was harvested using a skid-steer loader from the 12 feedpens (8-hd each) that were paved with 6-8 inches of hydrated compacted mixture of fly ash & crushed bottom ash from a coal-fired power plant. Similarly, the manure was harvested from the 6 unpaved soil-surfaced 8-hd pens. The 12 paved pens produced 85,000 lbs as-collected weight of FB (called LA-FB), or an average of 7,083 lbs/pen. The 6 un-paved (traditional soil-surfaced) pens yielded (56,000 lbs as-collected weight or 9,333 lbs/pen called HA-FB). The bulk as-collected manure was placed in two separate windrows according to type of pen surfacing material (LA-FB or HA-FB). A bulk sample of un-composted manure from the paved feedpen surfaces, which we termed low-ash feedlot biomass (LA-FB) was collected from the windrow (10 sub-samples) using the skid loader prior to the start of composting (~952.5 kg, or 2,100 lbs.). This material was coarsely ground in a small hammer mill and placed in a greenhouse on June 2, and June 8, 2005 to facilitate drying. Similarly, the stockpiled un-composted manure from the un-paved feedpen surfaces, which we termed high-ash feedlot biomass (HA-FB), was randomly collected (10 sub-samples) prior to the start of composting (~317.5 kg or 700 lbs bulk sample), coarsely ground in the small hammer mill, and placed in the greenhouse on June 10, 2005 for drying. Three composite (2 kg) samples composed of 10 sub-samples each of the un-composted as-collected LA-FB and HA-FB were taken before and after grinding just prior to greenhouse drying and submitted for analysis.

Partial Composting

Because of the low moisture content of the as-collected FB, water was added to start the composting process. Approximately 3,000 gallons of water was added on June 9, 2005 to the LA-FB windrow; and following heavy rainfall, approximately 800 gallons of water was added to the HA-FB windrow on June 13, 2005. The LA-FB and HA-FB was partially composted (PC) for 55 days and 51 days, respectively. Samples were removed from both windrows on August 2, 2005. These composite samples (2 kg each) were submitted for analysis.

Grinding

The bulk samples of LA-FB and HA-FB collected both prior to and after partial composting was processed by a hammer mill and dried in a greenhouse to <10% moisture (wb). Then, for the PC materials, approximately 3,400-3,800 lbs of the LA-FB-PC, and 1,000 lbs of HA-FB-PC cattle manure was processed (pulverized) in a Vortec Impact Mill ® (Vortec Mfg. Co., Long Beach, CA) to further reduce the overall particle size for combustion testing.

Analysis

Random samples (n=3) were extracted from 10 sub-samples collected from each type of FB material: LA-FB, HA-FB, LA-FB-PC, and HA-FB-PC. These samples were sent to Hazen Research Inc., Golden, CO for analysis. Proximate & ultimate analysis, elemental analysis of ash-residue, and trace minerals (S, P, Cl, Na, metals, etc.) were obtained. For analysis of metals and elemental analysis of ash, only one composite sample was analyzed for each type of manure.

Bulk Density

Following the initial bulk sampling of harvested manure from the feedpens, bulk density of material in both windrows was determined. Bulk density was determined by two alternative standard methods: ASAE standard S269.4 and ASTM standard D1895 B. ASAE standards method S269.4 was modified slightly by using a 0.028m^3 (1 ft^3) wood container with inside dimensions of 30.5 x 30.5 x 30.5 cm. rather than a 0.057 m^3 (2 ft^3) specified container size. The ASAE standard required the material to be poured from a height of 61cm (2 ft) until the container was filled. Once the container was filled, all excess material was scraped off with a strait edge level with the top of the container to establish a 1 ft^3 struck volume of material. The material was then dropped 5 times from a height of 15.24 cm (6 inches). Each time the container was dropped, and FB would settle; more FB was added to the container and struck level with the surface and then the process was repeated. The manure was weighed after the fifth drop and addition of FB. This test was repeated 3 times with random samples each of the HA-FB and LA-FB. Three samples each of the LA-FB and HA-FB were taken to determine gravimetrical moisture content after 24 hours at 75°C in a drying oven.

The ASTM standard D 1895 B required the material to be compacted in a know volume. The material was poured from a height of 61cm (2 ft) until the container was filled. Once the container was filled, all excess material was scraped off with a strait edge level with the top of the container, and then weighed. This test was repeated 3 times with random samples of the FA-FB and 3 times with random samples of the HA-FB. Three samples of the LA-FB and 3 samples of the HA-FB were taken to determine moisture content, which was determined gravimetrically after drying for 24 hours at 75°C in a drying oven.

Results and Discussion

Un-composted Feedlot Biomass

Results were compared for unpaved vs. paved feedlot surface and for un-composed vs. partially composted FB. Bulk densities were determined only for the un-composted FB, which showed major differences as a function of pen surfacing material. LA-FB from paved feedlots had a bulk density only two-thirds that of HA-FB from un-paved/soil-surfaced feedlots. Specifically, bulk density of LA-FB (at a moisture content of 6.40 +/- 0.24 % w.b.) averaged 31.97 +/- 0.29 lbs/cu.ft. using the modified ASAE standard and 26.81 +/- 0.03 lbs/cu.ft. using the ASTM standard. By contrast, HA-FB (at 4.95 +/- 0.02 % moisture w.b.) exhibited bulk densities of 46.65 +/- 0.86 lbs/cu.ft. with the modified ASAE standard and 40.61 +/- 0.71 lbs/cu.ft. with the ASTM standard. The packed FB materials (5 drops from 6 inches and refills) resulting from the modified ASAE standard exceeded that of the unpacked FB material from the ASTM method by approximately 19% and 15%, respectively, for LA-FB and HA-FB.

Moisture content was similar for the as-collected HA-FB and LA-FB (~20% w.b.) prior to composting, as shown in Table 1. But HA-FB was much greater in ash content (58.73% vs. 20.20 % d.b.) and had only half the volatile matter (33.77 vs. 64.56% d.b.) and fixed carbon (7.50 vs. 15.24% d.b.) as LA-FB,. Consequently, the higher heating value (HHV) was much lower (about half) for the HA-FB than for LA-FB, both on an as-received basis (2,710 +/- 34 vs. 5,764 +/- 147 BTU/lb w.b.) and dry basis (3,380 +/- 14 vs. 7,229 +/- 92 BTU/lb d.b.). The LA-FB showed about 10% higher HHV on a dry ash free (DAF) basis as compared to HA-FB (9,059 +/- 13 vs. 8,200 +/- 327 BTU/lb DAF). Not surprisingly, LA-FB contained about twice the total carbon and hydrogen as HA-FB, and about 50% higher N and S. However, expressed on an energy basis (lbs S per million BTU), sulfur content was lower in the LA-FB. Chlorine content of the manure was essentially the same for both HA-FB and LA-FB (average of 0.376% d.b.).

As shown in Table 2, un-composted FB displayed differences in elemental composition of sample-ash depending on type of feedlot surfacing material. Compared to HA-FB, the LA-FB appeared to contain lower Si, Al, Fe and Ti, but was higher in Ca, Mg, Na, K, P, S, Cl, and Ba. These results should be interpreted with caution as they were based on only on composite sample per FB type.

Partially Composted (PC) Feedlot Biomass

Proximate analysis showed that both PC materials were similar in moisture 17.0 and 19.6% w.b. for HA-FB-PC and LA-FB-PC, respectively (Table 3). On a dry basis the LA-FB-PC, had only 1/3 as much ash, twice the volatiles, and more than 3 times the Fixed Carbon as HA-FB-PC. Higher Heating Values (HHV, BTU/lb), showed major differences as well. LA-FB-PC had 164% higher HHV as HA-FB-PC (d.b.) and 16% higher heating value on a dry-ash free (DAF) basis as HA-FB-PC. Ultimate analysis showed that LA-FB-PC had over twice the total Carbon and Hydrogen as HA-FB-PC, which contribute to heating value, but also twice the oxygen which suppresses HHV. LA-FB-PC contained 80% more Nitrogen than HA-FB-PC, improving its usefulness for reburn fuel applications, but LA-FB-PC had 68% more sulfur than HA-FB -PC. LA-FB-PC had more than twice the Cl than HA-FB-PC and 74% higher phosphorus. On a heating value basis, LA-FB-PC had only 1/8 the ash and only 2/3 the S as HA-FB-PC.

Compared to HA-FB-PC, as shown in Table 2, sample-ash from partially-composted LA-FB contained 2/3 less silica and less than half the Al, Ti and Fe. However, LA-FB-PC contained 2-3 times more Ca, Mg, Na, K, and S than HA-FB-PC and it was nearly 5-times higher in P and an order of magnitude higher in Cl. However, metals appeared to be more similar, with HA-FB-PC slightly higher in As and Pb and lower in Cd, compared to LA-FB-PC.

Comparisons of un-composted and partially composted FB are shown in Table 4. Partial composting for 51–55 days increased ash and further reduced volatile matter, fixed C, total C, hydrogen and N both in HA-FB-PC and LA-FB-PC, compared to un-composted FB sources. Partial composting reduced HHV by 20% in HA- FB and only 2% in LA-FB. Sulfur content was changed very slightly with partial composting, but inexplicably the Cl content increased in the LA-FB-PC. Results did not indicate major differences in elemental composition of sample-ash for either HA-FB or LA-FB resulting from partial composting, but insufficient data was available to detect trends.

Comparison with Coal & Lignite

For comparison, samples of Texas lignite (TXL) and Wyoming Powder River Basin (PBR) coal were analyzed in the same manner as the FB materials. As shown in Table 5, moisture contents were 38.34 +/- 0.34% w.b. and 32.88 +/- 0.36 % w.b. respectively, which is considerably higher than for the FB materials of Tables 1, 3 and 4. Ash contents were much lower for the coal 8.40 +/- 3.11% d.b. vs. 18. 59 +/- 0.85% d.b. for TXL. The latter value is only slightly lower than for LA-FB and LA-FB-PC. Sulfur was higher (0.98 +/- 0.15% d.b.) in TXL than for PRB coal (0.41 +/-0.03 % d.b.) or either of the FB sources. On a dry matter basis, total carbon was much higher for TXL and PRB coal (60.30 +/-0 0.92 % and 69.32 +/- 2.82 % d.b., respectively) than either LA-FB or HA-FB. N was slightly lower and P and Cl much lower for either TXL or PRB coal compared to LA-FB or HA-FB. As expected compared to feedlot biomass, HHV was considerably higher for both TXL and PRB coal on an as-received basis (6,143 +/- 127 BTU/lb w.b. and 7,823 +/- 282 BTU/lb w.b.); dry basis (9,962 +/-170 and 11,657 +/- 455 BTU/lb d.b.); and DAF basis (12,236 +/- 84 vs. 12,724 +/- 97 BTU/lb DAF). Elemental ash analyses appeared similar for TXL and PRB coal, but with differences vs. FB for several parameters. Additional analyses will be needed to verify any trends.

Subsequent Testing with HA-FB and LA-FB-PC Materials

A residual 39,000 lbs bulk sample from the HA-FB windrow was provided in July, 2005 to a commercial company (Panda Energy Group) for use in commercial fluidized-bed combustion pilot plant test burns in Idaho. Mixtures of HA-FB and cotton gin residue (CGR) were used at weight ratios of 100/0, 75/25, & 50/50 in Idaho. Resulting fluidized-bed combustion ash (18,000 lbs) was returned to TAES-Amarillo for further testing in cooperation with West Texas A&M University (WTAMU) (Megel et al. 2006,) to determine engineering properties and soil fertility value.

The processed LA-FB-PC material was subsequently used to evaluate various reburn fuel injector configurations with pulverized coal: FB fuel blends of 90:10; 50:50 or 100:0%, conducted by the Texas Engineering Experiment Station (TEES) (Annamalai et al, 2006). Procedures and results of these tests are beyond the scope of the present paper.

Summary and Conclusions

1. Major differences (dry-matter basis) were determined between HA-FB and LA-FB for the following parameters: ash -- 58.7 vs. 20.2%; volatile matter --33.8 vs. 64.6%; fixed carbon -- 7.5 vs. 15.2%; heating value (HHV) -- 3,380 vs. 7,229 BTU/lb; N -- 1.91 vs. 3.11%; S --0.42 vs. 0.67% while Cl was similar (~0.38%).
2. Bulk density of LA-FB was 2/3 that of HA-FB, averaging 29 vs. 44 lbs/ft^3 depending on methods used.
3. Ash content of LA-FB was about one-third that of HA-FB (20% vs. 59%).
4. Elemental analysis of sample ash from LA-FB was higher than from HA-FB in Ca, P, Cl, K, Mg, Na, and S, but was lower in Si, Al, Ti, and Fe without or with partial composting. However, metals contents were similar for both sources of FB.
5. Partial composting increased ash; reduced C & N; and lowered HHV by 2% and 20% for LA-FB-PC and HA-FB-PC, respectively.
6. Project data on feedlot manure characteristics was used by a commercial company to design a feedlot biomass (FB)/ cotton gin residue (CGP) combustion facility to provide heat energy to an ethanol plant near Hereford, TX.
7. Heating value on a dry-ash free DAF-basis averaged 8,995 BTU/lb for LA-FB-PC, and averaged 7,941 BTU/lb for HA-FB-PC.

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Table 1. Proximate and Ultimate Analysis of As-Collected (Un-composted) Feedlot Biomass Harvested from a) Soil-Surfaced (SS) Cattle feedpens (n=6) (HA-FB) and b) Crushed Fly Ash (FA) feedpens (n=12) (LA-FB)

	Soil-Surfaced Feedpens (n=6), HA-FB				**Crushed Fly Ash-Surfaced Feedpens (n=12), LA-FB**			
	Harvesting Date = 6/10/05				Harvesting Date = 6/1/05			
Parameter	**SS 101-103**		**SS101-103**		**FA104-106**		**FA104-106**	
	As-Received %		Dry, %		As-Received %		Dry, %	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Proximate:								
Moisture	19.81	1.24	0	0	20.27	1.27	0	0
Ash	47.10	1.29	58.73	1.65	16.10	0.73	20.20	1.11
Volatile	27.08	1.25	33.77	1.26	51.47	1.34	64.56	0.94
Fixed C	6.02	0.36	7.50	0.45	12.16	0.40	15.24	0.27
Total	100.01		100.00		100.00		100.00	
Heating Value								
HHV, BTU/lb	2710	34	3380	14	5764	147	7229	92
MMF, BTU/lb	5505	174	9259	457	6969	133	9247	26
MAF/DAF, BTU/lb			8200	327			9059	13
Ultimate:								
Moisture	19.81	1.24	0	0	20.27	1.23	0	0
Carbon	17.39	0.9	21.69	1.14	34.35	0.77	43.09	0.49
Hydrogen	2.1	0.10	2.62	0.13	4..17	0.11	5.22	0.05
Nitrogen	1.56	0.04	1.94	0.07	2.48	0.04	3.11	0.03
Sulfur	0.34	0.02	0.42	0.02	0.53	0.02	0.67	0.01
Ash	47.1	1.29	58.73	1.65	16.10	0.73	20.20	1.11
Oxygen (diff.)	11.7	0.82	14.59	0.81	22.10	0.80	27.70	0.63
Total	100.00		99.99		100.00		99.99	
Chlorine	**SS 101-103 Composite**				**FA 104-106 Composite**			
Chlorine, Cl	0.301		0.375		0.302		0.377	
Phosphorus								
Phosphorus (Ash Basis), P205, %			2.74	0.08			12.87	0.85
Phosphorus (Dry Basis), P205, %			1.61	0.04			2.59	0.04
Contaminants, Energy Basis:								
Ash, lbs/MM BTU			173.78	5.13			27.96	1.89
SO2, lbs/MM BTU			2.51	0.13			1.86	0.05

Table 2. Elemental Analysis of FB Sample Ash from As-Collected/Un-composted FB from Un-Paved & Paved Pens (HA-FB and LA-FB), from Partially Composted FB (HA-FB-PC and LA-FB-PC), and from Texas Lignite and PRB Coal, 2005.

Ash Elemental Analysis* (%), Equal-Weight-Composite (n=1)						
	HA-FB, %, Dry Basis	LA-FB, %, Dry Basis	HA-FB-PC, %, Dry Basis	LA-FB-PC, %, Dry Basis	TXL %, Dry Basis	PBB Coal %, Dry Basis
Silicon, Si02	64.68	25.55	65.55	20.78	48.72	31.73
Aluminum, Al203	7.72	1.94	11.2	4.94	16.04	17.27
Titanium, Ti02	0.44	0.27	0.52	0.22	0.85	1.35
Iron, Fe203	2.90	1.37	2.99	1.71	7.44	4.61
Calcium, Ca0	7.09	20.20	7.47	21.0	11.70	22.20
Magnesium, Mg0	2.34	7.17	2.29	7.54	1.93	5.62
Sodium, Na20	1.38	4.94	1.38	5.26	0.29	1.43
Potassium, K20	4.50	12.70	4.66	14.60	0.61	0.67
Phosphorus, P205	2.81	11.11	2.43	13.77	0.10	0.80
Sulfur, S03	1.06	4.46	1.30	4.47	10.80	10.40
Chlorine, Cl	0.68	5.02	0.41	5.07	<0.01	<0.01
Carbon Dioxide, C02	1.35	1.71	0.51	0.59	0.08	0.37
Total Ash Analysis	96.95	96.44	100.71	99.95	98.56	96.45
Metals in Ash (mg/kg) equal-weight (n=1)						
Arsenic	4.12	3.96	3.85	2.81	24.7	17.6
Barium	669	2,620	800	700	1,590	6,230
Cadmium	<1	2	3.8	8.2	3.4	5.2
Chromium	<20	20	30	40	98	110
Lead	20	20	27	15	47	130
Mercury	<0.01	<0.01	0.03	0.04	0.01	<0.01
Selenium	<2	2	<2	4	<2	<2
Silver	<2	<2	<2	<2	<2	<2
Total Metals in Ash	693.12	2,667.96	864.68	770.05	1,763.11	6,492.80

*** Data represents one composite (n=1) of 3 samples of each FB material, or of lignite and coal.**

**** FB, TXL or PRB Coal were calcined @ 1100 deg. F (600 deg. C) prior to analysis.**

Table 3. Proximate and Ultimate Analysis of Partially-Composted (PC) Manure Feedlot Biomass Harvested from Soil-Surfaced Feedpens (n=6) HA-FB vs. Crushed Fly Ash-Surfaced Feedpens (n=12) LA-FB (Sampled 8/2/05).

	Soil-Surfaced Feedpens (n=6)				**Crushed Fly Ash Surfaced Feedpens (n=12)**			
	HA-FB-PC, 51 Days Composting				LA-FB-PC, 55 Days Composting			
Parameter	SS 107-109		SS 107-109		FA 110 -112		FA 110-112	
	As-Received %		Dry, %		As-Received %		Dry, %	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Proximate:								
Moisture	17.00	0.26	0	0	19.64	2.54	0	0
Ash	53.85	0.77	64.88	0.74	16.50	0.28	20.53	0.52
Volatile	25.79	1.04	31.07	1.31	52.33	2.12	65.11	0.59
Fixed C	3.36	0.78	4.05	0.95	11.54	0.32	14.36	0.28
Total	100.00		100.00		100.01		100.00	
Heating Value:								
HHV, BTU/lb	2239	49	2697	60	5704	192	7097	17
MMF, BTU/lb	5336	134	9015	228	6933	250	9119	45
MAF/DAF, BTU/lb			7682	169			8931	38
Ultimate:								
Moisture	17.00	0.26	0	0	19.64	2.54	0	0
Carbon	14.92	0.16	17.97	0.25	33.79	1.10	42.05	0.14
Hydrogen	1.39	0.08	1.68	0.10	3.65	0.30	4.55	0.29
Nitrogen	1.13	0.02	1.36	0.03	1.97	0.07	2.45	0.02
Sulfur	0.31	0.02	0.38	0.02	0.51	0.02	0.64	0.04
Ash	53.85	0.77	64.88	0.74	16.50	0.28	20.53	0.52
Oxygen (diff.)	11.40	0.27	13.73	0.37	23.94	1.03	29.78	0.36
Total	100.00		100.00		100.00		100.00	
Chlorine	**SS 107-109 Composite**				**FA 110-112 Composite**			
Chlorine, Cl	0.281		0.338		0.727		0.905	
Phosphorus								
Phosphorus (Ash Basis), P205, %			2.43	0.05			13.30	0.69
Phosphorus (Dry Basis), P205, %			1.57	0.01			2.73	0.11
Contaminants, Energy Basis:								
Ash, lbs/MM BTU			240.66	7.13			28.94	0.81
SO2, lbs/MM BTU			2.79	0.13			1.79	0.11

Table 4. Comparison (Dry Basis) of Un-Composted and Partially-Composted FB from Soil Surfaced & Crushed Fly Ash Feedpens.

	Soil-Surfaced (SS) Feedpens (n=6) HA-FB				Crushed Fly Ash-Surfaced (FA)			
	Before composting		8/2/05 – 51 day compost		Before composting		8/2/05 – 55 day compost	
Parameter	**SS 101-103**		**SS 107-109**		**FA 104 -106**		**FA 110-112**	
	Dry, %		Dry, %		Dry, %		Dry, %	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Proximate:								
Moisture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ash	58.73	1.65	64.88	0.74	20.20	1.11	20.53	0.52
Volatile	33.77	1.26	31.07	1.31	64.56	0.94	65.11	0.59
Fixed C	7.50	0.45	4.05	0.95	15.24	0.27	14.36	0.28
Total	100.00		100.00		100.00		100.00	
HHV, BTU/lb	3,380	14	2697	60	7229	92	7097	17
MMF, BTU/lb	9,259	457	9015	228	9247	26	9119	45
MAF/DAF, BTU/lb	8,200	327	7682	169	9056	13	8931	38
Ultimate:								
Moisture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon	21.69	1.14	17.97	0.25	43.09	0.49	42.05	0.14
Hydrogen	2.62	0.13	1.68	0.10	5.22	0.05	4.55	0.29
Nitrogen	1.94	0.07	1.36	0.03	3.11	0.03	2.45	0.02
Sulfur	0.42	0.02	0.38	0.02	0.67	0.01	0.64	0.04
Ash	58.73	1.65	64.88	0.74	20.20	1.11	20.53	0.52
Oxygen (diff.)	14.59	0.81	13.73	0.37	27.70	0.63	29.78	0.36
Total	99.99		100.00		99.99		100.00	
Chlorine One Composite of 3 samples per FB Type								
Chlorine, Cl	0.375		0.338		0.377		0.905	
Phosphorus, P_2o5%								
P-Ash Basis	2.74	0.08	2.43	0.05	12.87	0.85	13.30	0.69
P-Dry Basis	1.04	0.04	1.57	0.01	2.59	0.04	2.73	0.11
Contaminants, Energy Basis:								
Ash, lbs/MM BTU	173.78	5.13	240.66	7.13	27.96	1.89	28.94	0.81
SO2, lbs/MM BTU	2.51	0.13	2.79	0.13	1.86	0.05	1.79	0.11

Table 5. Texas Lignite (TXL) and Wyoming Powder River Basin (PRB) Coal*

Parameter	**TXL 113-115 (n=3)**		**TXL 113-115 (n=3)**		**PRB 116-118 (n=3)**		**PRB 116-118 (n=3)**	
	As-Received %		Dry, %		As-Received %		Dry, %	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Proximate:								
Moisture	38.34	0.34	0.00	0.00	32.88	0.36	0.00	0.00
Ash	11.46	0.50	18.59	0.85	5.64	2.11	8.40	3.11
Volatile	24.79	0.26	40.20	0.53	28.49	0.62	42.45	1.02
0.45Fixed C	25.41	0.63	41.21	0.80	32.99	1.31	49.15	2.15
Total	100.00		100.00		100.00		100.00	
Heating Value								
HHV, BTU/lb	6143	127	9962	170	7823	282	11657	455
MMF, BTU/lb	7003	109	12487	70	8328	121	12828	81
MAF/DAF, BTU/lb			12236	84			12724	97
Ultimate:								
Moisture	38.34	0.34	0.00	0.00	32.88	0.36	0.00	0.00
Carbon	37.18	0.66	60.30	0.92	46.52	1.74	69.32	2.82
Hydrogen	2.12	0.08	3.44	0.14	2.73	0.07	4.06	0.13
Nitrogen	0.68	0.01	1.11	0.02	0.66	0.03	0.98	0.04
Sulfur	0.61	0.09	0.98	0.15	0.27	0.02	0.41	0.03
Ash	11.46	0.50	18.59	0.85	5.65	2.11	8.40	3.11
Oxygen (diff.)	9.61	0.32	15.58	0.44	11.29	0.14	16.83	0.29
Total	100.00		100.00		100.00		100.00	
Chlorine One Composite of 3 samples								
Chlorine, Cl	0.01		0.016		0.009		0.013	
Phosphorus								
P-Ash Basis, P$_2$05, %			0.13	0.01			0.57	0.14
P-Dry Basis, P$_2$05, %			0.02	0.00			0.05	0.01
Contaminants, Energy Basis:								
Ash, lbs/MM BTU			18.67	1.17			7.28	3.02
SO2, lbs/MM BTU			1.98	0.32			0.70	0.02

* Lignite and coal samples provided by TXU Energy, Dallas , TX; Sampling Date = 10/10/05. Data are means and standard deviations of 3 samples of each material.