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**Texas Commission on Environmental Quality**
**New Technology Research & Development (NTRD) Program**
**Monthly Project Status Report**

**Title:** FEEDLOT BIOMASS: A REBURN FUEL FOR “MAXIMUM NOX” REDUCTION IN COAL-FIRED POWER PLANTS

**Contract Number:** TCEQ Grant # 582-5-65591 0015

**Grantee:** Texas Engineering Experiment Station, Texas A&M University

**Date Submitted**: December 09, 2005

**Report for the Monthly period**:
**Starting Date**: November 1, 2005 **Ending Date:** November 30, 2005

**Section I. Accomplishments (*Please provide a bulleted list of project accomplishments as well as a description of their importance to the project.)***

The overall objectives of the project are i) to develop a retrofit technology of using processed low-ash feedlot biomass (FB) as reburn fuel for potential reduction of the NOx in coal-fired power plants by 80-90% and ii) determine the possible capture of Hg for low rank coals, reduction of $CO_2$ and other benefits of using animal wastes (alternately known as feedlot biomass, FB) as fuels.

In this report, the task lists are summarized and the progress/accomplishments for each task is reported

**Task 1: Fuel Characteristics of lignite, sub-bituminous coal, raw manure (RM), and partially composted manure (PC)**

**2.1. Task Statement: The PERFORMING PARTY will analyze the fuel characteristics of raw manure (RM), and partially composted manure (PC).**

**2.1.1 The following four groups of FB will be selected: HA-RM (high-ash raw manure from Conventional lots), LA-RM (low-ash raw manure), HA-PC (high-ash PC), and LA-PC (low-ash PC). The LA-RM includes those collected from ash paved feedlots (25% ash) near Amarillo, TX and dairy farms (15-20% ash) located near Waco, TX. The conventional soil surface HA-FB will be obtained from the feed yards near Amarillo, Texas, while the LA-FB will be obtained from the Texas Agricultural Experiment Station (USDA-ARS Experimental Feedyard at Bushland, TX. Partially composted Dairy Biomass (DB) will be obtained from Dairy farms around Waco, TX. All fuel including FB and DB will be dried and ground, and shipped from Amarillo to TAMU facility at College Station, TX and DOE Pilot Facility at Pittsburgh, PA; Wyoming and Lignite coal will be ground and shipped to TAMU and DOE Pilot Facility, Pittsburgh**.

**<u>Progress To date:</u>**

All the necessary fuels HA-RM, LA-RM, HA-PC and LA-PC have been collected, dried and ground. They have been shipped to TAMU facility at College Station, TX. Wyoming and Lignite coal have been ground and shipped to TAMU. However pilot plant selection have not yet been decided and hence fuel sample have not yet been shipped any pilot scale facility.

2.1.1.1 All samples will be tested for moisture and ash content by the PERFORMING PARTY at the TAES/ARS Research and Production Laboratory at Bushland, Texas. Ultimate analyses including the heating values will be performed on all fuel samples. Ash analyses will also be performed on all the four types of FB fuels (including elements like Na, Fe, K, P, S and others) in order to interpret whether any variation in these elements amongst all the four types affect the pyrolysis, reburning, and fouling processes.

**Progress To date**:

All the fuels HA-RM, LA-RM, HA-PC and LA-PC have tested for moisture and ash content. They have been shipped to TAMU facility at College Station, TX. Ultimate analyses including the heating values have been performed (typically 3 samples for each fuel) on HA-RN, LA-RM, HA-PC and LA-PC, Wyoming and Lignite coals. Various heat value and emissions calculations were conducted for the two types of coal and compared to results of DB and FB obtained earlier. A spreadsheet showing the proximate, ultimate, and ash analysis as well as the calculations of each of the selected fuels (DB, FB, and Coal) is shown in the Appendix.

**2.1.1.2. Fundamental pyrolysis and ignition studies will be performed by the PERFORMING PARTY on all the four types of FB to generate data on kinetics of pyrolysis because of its relevance to reburn mechanism. Pyrolysis and ignition behavior studies will be performed for HA-RM, LA-RM, HA-PC, LA-PC and Coal: FB blends using Thermo Gravimetric Analyses (TGA).**

**Progress to date**

In order to model the processes for cofiring and reburn and understand the basic mechanisms governing the ignition behavior and NOx reduction with FB, fundamental experiments have been conducted to generate data on pyrolysis and ignition characteristics of FB and coal. Experiments were conducted in a Thermogravimetric Analyzer / Differential Thermal Analyzer (TGA/DTA) in both $N_2$ and air for coal, FB and coal: FB blends. In the past, Using the parallel reaction model, devolatilization kinetic constants were obtained by curve fitting the mass traces for pure pyrolysis of FB. TGA traces were obtained for HA-PC and LA-PC. When the experiments were repeated in air, coal exhibited a distinct mass loss trace different than N2, which is then used to interpret the ignition behavior. When the experiments were repeated for FB in air the trace was very similar to the N2 trace indicating no group ignition behavior for FB. All pyrolysis and ignition experiments were completed and 75% of the data was analyzed. Task 1 is 90% complete. Analyses and reporting remain to be completed

**2.1.2. Schedule: The PERFORMING PARTY shall complete this task within 8 months of the signed Notice to Proceed Date as issued by TCEQ.**

**Progress to date**
Progress is on schedule

**2.1.3. Deliverables: The PERFORMING PARTY shall submit a detailed written report to the TCEQ upon completion of this task, to include but not limited to a summary of the analyst of the fuel characteristics of raw manure and partially composted manure.**

**Progress to date**

Yet to be performed

**Task 2: Small Scale Reburn Experiments for NOx reduction**

**2.2. Task Statement: The PERFORMING PARTY will perform small scale reburn studies with fuels listed in Task 1 as reburn fuels except DB, RM and their blends. The conventional TAMU co-fired boiler burner facility will be used for the studies**.

**2.2.1 The PERFORMING PARTY shall modify the facility for reburn experiments. These modifications include 1) allow two different reburn injection schemes to enable better mixing with NOx laden streams; 2) Install a single-pass water tube heat exchanger just before the water quench system to cool the gases and study the fouling behavior; and 3) Install an air assisted injector system for injection of Hg Acetate solution to simulate Hg emission on the primary burn zone. For the following experiments, the NOx from the main burner will be reduced to 100-400 ppm. Gas temperatures in the reburn zone, and species concentration at exhaust will be measured. Process variables will include co-fired heat input, and reburn zone stoichiometric ratio (SR). Texas Lignite Coal will be used as the baseline main fuel. Parameters to be monitored as key performance indicators include emissions of NOx, SO2, CO, and CO2 and ash analyses (loss-on-ignition). The TGA analyses of FB determined from Task 1 will be used in interpreting the test data. Tests will be performed with fan type injectors to spread the FB throughout the cross section and at an upward angle in order to improve mixing and provide more residence time for NOx reduction. The mixing time scale will be determined by measuring the O2% when air is injected in the main burner while N2 is injected through the reburn nozzle**.

**Progress to date**

The facility has been modified for reburn tests. Preliminary reburn experiments have been performed. Task 2 is 20% complete. Detailed experiments await for problems the service of gas analyzer. A new gas conditioning setup was made to facilitate the measurement of exhaust gases. The frame for the new reactor for Hg studies is almost complete and should be delivered in mid December. Specified insulation for new furnace and are ready to order materials.
Current Status:

**2.2.1.1. The PERFORMING PARTY will investigate the effect of reburn zone equivalence-ratio for Texas Lignite, LA-PC, and blends of Texas lignite and LA-PC.**

**Progress to date**

Yet to be performed

**2.2.1.2. The PERFORMING PARTY will use N2 and air mixture in the reburn nozzle in order to simulate the exhaust gas recirculation (EGR) for injection of reburn fuel.**

**Progress to date**

Yet to be performed

**2.2.1.3. The PERFORMING PARTY will study the fouling potential, associated with FB as reburn fuel. During the combustion experiments, the PERFORMING PARTY will measure the water inlet temperature and exit temperature to determine the degree of ash deposition. The ash will be scraped off and sent for analyses.**

**Progress to date**

Yet to be performed

**2.2.1.4. The PERFORMING PARTY will conduct experiments for Hg Capture. Trace amounts of Hg acetate solution will be injected to simulate the Hg vapor in flue gases. The FB will be injected through reburn ports. Hg capture will be studied with and without the presence of heat exchangers. An Automatic Mercury Analyzer will be used for measurements of Hg (Hg0, Hg+2) emissions.**

**Progress to date**

Yet to be performed

**2.2.2. Schedule: The PERFORMING PARTY shall complete this task within 11 months of the signed Notice to Proceed Date as issued by TCEQ.**

**2.2.3. Deliverables: The PERFORMING PARTY shall submit a detailed written report to the TCEQ upon completion of this task, to include but not limited to a summary of the test results from the reburn studies. These results include the monitored emissions of NOx, SO2, CO, and CO2 and ash analyses as well as the results from the Mercury Analyzer.**

**Progress to date**

This task is behind our schedule due to untimely death of senior graduate student.

**Task 3: Pilot scale test at the 500,000 BTU/hr DOE-NETL facilities to verify the small-scale test data on NOx reduction and Hg capture and obtain optimum conditions.**

**2.3. Task Statement: The pilot plant at the Combustion and Environmental Research Facility (CERF) will bused for testing LA-RM and LA-PC fuels and measuring the NOx emissions. The PERFORMING PARTY will also obtain the optimum operating conditions and appropriate injector configuration.**

**2.3.1. Schedule: The PERFORMING PARTY shall complete this task within 9 months of the signed Notice to Proceed Date as issued by TCEQ.**

**2.3.2. Deliverables: The PERFORMING PARTY shall submit a detailed written report to the TCEQ upon completion of this task, to include but not limited to a summary of the pilot scale test and results of the NOx emissions.**

**Progress to date**

Yet to be performed. Task 3 will begin when results from Task 2 are obtained. Task 3 is 1% complete.

**Task 4: Reburn modeling to predict NOx capture by biomass fuels.**

**2.4. Task Statement: The PERFORMING PARTY will create a model for characterizing reburn performance with coal, FB and coal: FB blends in predicting NOx and as well as Hg control performance. This task will be conducted primarily using zero Dimensional reburn code with characteristic mixing time scale concept. The simplified model will provide directions for improvement of NOx capture and assist in developing the test matrix.**

**2.4.1. Schedule: The PERFORMING PARTY shall complete this task within 11 months of the signed Notice to Proceed Date as issued by TCEQ.**

**2.4.2. Deliverables: The PERFORMING PARTY shall submit a detailed written report to the TCEQ upon completion of this task, to include but not limited to a summary of the modeling.**

**Progress to date**

Most of the formulations on Zero D model have been completed and a computer program has been developed. A new student has been hired to replace the graduate student who had expired recently Modeling on Zero D reburn process is continuing. Some coding errors have caused delays.

The mercury modeling of single coal particle to date incorporated a single reaction mechanism give below.

$$Hg + 2HCl \rightarrow HgCl_2 + H_2$$

The simulations were carried out at two different temperatures by changing the concentration of chlorine present in coal and mercury concentration in coal is not changed. In this way, the effect of chlorine concentration on oxidation of mercury oxidation is being studied. The results showed mercury oxidation increases with chlorine concentration but mercury oxidized by chlorine is very small. The conclusion drawn from the results is that the single reaction mechanism used does not properly model the oxidation reaction. Presently we are implementing a three step reaction mechanism for the future simulation.

$$HCl + OH \rightarrow Cl + H2O$$
$$Hg + Cl \rightarrow HgCl$$
$$HgCl + Cl \rightarrow HgCl2$$

Task 4 is 30% complete.

**Task 5: Perform the economics of the use of FB as reburn fuel in coal fired power plants and cost of NOx reduction compared to other technologies.**

**2.5. Task Statement: The PERFORMING PARTY will conduct an economic analysis for all four biomass fuels listed in Task 1.**

**2.5.1.1. The following will be calculated: 1) required coal and reburn fuel firing rate, 2) the ash production, 3) the dollar and CO2 savings in using feedlot biomass, and 4) maximum radius of economical use of feedlot biomass.**

**2.5.1.2. The PERFORMING PARTY will conduct an analysis of the benefits and limitations of using Selective Non Catalytic Reduction and Catalytic Reduction for NOx reductions.**

**2.5.2. Schedule: The PERFORMING PARTY shall complete this task within 11 months of the signed Notice to Proceed Date as issued by TCEQ.**

**2.5.3. Deliverables: The PERFORMING PARTY shall submit a detailed written report to the TCEQ upon completion of this task, to include but not limited to a summary of the economic analysis including the benefit analysis of using Selective Non-Catalytic Reduction and Catalytic Reduction for NOx reductions.**

**<u>Progress to date</u>**

A spread sheet program has been developed already. Research has been conducted on the limitations of SNCR and SCR for coal fired power plants. CO2 savings in using FB are yet to be computed. Some minor discussion of the maximum radius of the economical use for feedlot biomass as a reburn fuel is still required. A comparison of SNCR and SCR to using FB as a reburn fuel is yet to be conducted.

Task 5 is 60% complete.

Indicate which part of the Grant Activities as defined in the grant agreement, the above accomplishments are related to:

**Current status and progress on all tasks are reported**

Section II: Problems/Solutions

| | |
|---|---|
| Problem(s) Identified<br><br>(*Please report anticipated or unanticipated problem(s) encountered and its effect on the progress of the project)* | **Task 1:**<br>**Task 2:**<br>Problems with the emissions measurement equipment prevented experiments from being conducted. Equipment has been sent for repairs and should be operational by mid December. The arrival of gas analyzers sent for Factory repair/service is delayed due to problems at the factory in timely delivery of spare parts for the analyzer**.**<br>**Task 3:**<br>No Progress. Waiting on arrival of Hg equipment<br>**Task 4:**<br>Waiting for hiring for replacement of deceased student.<br>The use of current kinetics on Hg oxidation in single particle model results in negligible levels of HgCl2 due to extremely low concentrations of Hg and $Cl_2$**.**<br>**Task 5:**<br>**i. None** |
| Proposed Solution(s)<br><br>*(Please report any possible solution(s) to the problem(s) that were considered/encountered)* | **Tasks 2 and 3:** If delay of delivery of gas analyzers persists, we have planned to rent gas analyzer in order to continue with the task**.** A PhD student may be needed to replace the deceased PhD student in order to accelerate the progress on Hg aspect of task<br><br>**Task 3:** Contacts were made with Ducon Technologies to accelerate the delivery.<br><br>**Task 4:** A graduate student may be needed to accelerate the progress on the Zero D reburn model. Since the reaction between atomic Cl and Hg is fast, and the flame temperatures are high, the use of reaction kinetics between Hg and atomic Cl is being explored |
| Action(s) Conducted and Results<br><br>*(Please describe the action(s) taken to resolve the problem(s) and its effect)* | **Tasks 2 and 3;** The Hg equipment has been recently delivered. A PhD student has been hired. He will start in Jan 2006.<br>**Task 4:** An MS student has been hired to accelerate the progress on the Zero D reburn model. Since the reaction between atomic Cl and Hg is fast, and the flame temperatures are high, the use of reaction kinetics between Hg and atomic Cl is being explored |

Section III. **Goals and Issues for Succeeding Period**: (*Please provide a brief description of the goal(s) you hope to realize in the coming period and identify any notable challenges that can be foreseen)*

**Next Month's Goals**

**Task 1:** Complete all analyses and reporting.

**Task 2:** Complete 25% of NOx reburn experiments. Purchase all furnace materials and begin assembly of new furnace.

**Task 3:** Contact pilot facilities to set up a time when experiments can be conducted

**Task 4**: Complete an additional 20% of the code.

**Task 5:** Compute CO2 savings; Continue to research the limitations of SNCR and SCR for coal fire power plants. Compare NOx reductions and cost of SNCR and SCR to those obtained or predicted from using feedlot biomass (FB) as a reburn fuel

______________________________________ **Date: 12/09/05**

**Authorized Project Representative's Signature**

**NOTE: Please attach any additional information that you feel should be a part of your report or that may be required to meet the deliverable requirements for tasks completed during this reporting period.**

## LIST OF ACRONYMS

**AB: Agricultural Biomass**
**AC: Activated Carbon**
**ACI: activated carbon injection**
**APCD: Air Pollution Control Devices**
**APH: Air Pre-heater**
**AW: Agricultural Wastes**
**ARS: Agricultural Research Station**
**ATP: Texas Advanced Technology Program**
**AWDF: Animal Waste Derived Biomass Fuels**
**CAFO: Concentrated Animal Feeding Operations**
**CAIR: Clean air Interstate Rule**
**CAMR: Clean Air Mercury Rule**
**CB: Cattle biomass**
**$CO_2$: Carbon Dioxide**
**DAF: Dry Ash Free**

**DB: Dairy Biomass**
**DOE: Department of Energy**
**DSC: Differential Scanning Calorimeter**
**EER: Energy and Environmental research Corp.**
**EGR: Exhaust Gas Recirculation**
**EPA: Environmental Protection Agency**
**ESP: electrostatic Precipitator**
**FB: Feedlot biomass (Cattle manure or Cattle Biomass CB)**
**FC: Fixed Carbon**
**FGD: flue gas Desulfurizer**
**FR: Feed Ration**
**GRA: Graduate Research Assistant**
**HA-FB-Raw: High Ash Feedlot Biomass Raw form**
**HA-FB-PC: High Ash Feedlot Biomass Partially Composted**
**HAHP: high ash/High Phosphorus feedlot biomass**
**HP: High Phosphorus**
**HHV: Higher Heating Value**
**HV: Heating value**
**LA-FB-Raw: Low Ash Feedlot Biomass**
**LA-FB-PC: Low Ash Feedlot Biomass Partially Composted**
**LALP: Low ash/Low Phosphorus feedlot biomass**
**LAHP: Low ash/High Phosphorus feedlot biomass**
**LOI: Loss on ignition or % carbon in bottom and fly ash**
**LP: Low Phosphorus**
**MAF: Moisture Ash Free, Dry Ash Free**
**mmBTU: million BTU**
**MMF: Mineral Matter Free**
**NETL: National Energy Technology Lab.**
**N2: Nitrogen**
**NOx: Oxides of Nitrogen**
**O2: Oxygen**
**PAC: powdered activated carbon**
**PCD: particulate control devices**
**PM: particulate matter**
**RM; Raw Manure**
**S: Sulfur**
**SCR: Selective catalytic reduction**
**SR: Stoichiometric ratio, AF/ $AF_{stoich}$**
**TAMU: Texas A&M University**
**TAES: Texas Agricultural Extension Service**
**TGA: Thermo-Gravimetric Analysis**
**TMPA: Texas Municipal Power Agency**
**TXU: Texas Utilities**
**USDA: US Dept of Agriculture**
**VM: Volatile matter**

## Appendix A: FUEL PROPERTIES

| Properties of the Fuels | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Parameter | Separated DB Solid | PC-DB 3-4 weeks Windrow | FCP-DB 3-4 month | Flushed DB | HA-FB-Raw | LA-FB-Raw | TXL AVG-3 samples | Wyoming PRB AVG-3 samples |
| Dry Loss (% Moisture) | 80.94 | 76.01 | 57.40 | 93.31 | 19.81 | 20.27 | 38.34 | 32.88 |
| Ash | 2.14 | 3.26 | 13.12 | 3.43 | 47.10 | 16.10 | 11.46 | 5.64 |
| FC | 3.64 | 4.83 | 7.04 | 0.45 | 6.02 | 12.16 | 25.41 | 32.99 |
| VM | 13.28 | 15.90 | 22.44 | 2.81 | 27.08 | 51.47 | 24.79 | 28.49 |
| Carbon, C | 9.39 | 11.44 | 16.25 | 1.85 | 17.39 | 34.35 | 37.18 | 46.52 |
| Hydrogen, H | 0.98 | 1.09 | 1.46 | 0.17 | 2.10 | 4.17 | 2.12 | 2.73 |
| Nitrogen, N | 0.36 | 0.51 | 0.92 | 0.16 | 1.56 | 2.48 | 0.68 | 0.66 |
| Oxygen, O (diff) | 6.14 | 7.64 | 10.70 | 1.04 | 11.70 | 22.10 | 9.61 | 11.29 |
| Sulfur, S | 0.05 | 0.05 | 0.15 | 0.04 | 0.34 | 0.53 | 0.61 | 0.27 |
| HHV (kJ/kg) | 3467.57 | 4266.00 | 5964.97 | 668.45 | 6303.46 | 13407.06 | 14286.82 | 18193.02 |
| Chlorine, Cl | 0.024 | | | | 0.301 | 0.302 | 0.010 | 0.009 |
| | Separated DB Solid | PC-DB 3-4 weeks Windrow | FCP-DB 3-4 month | Flushed DB | HA-FB-Raw | LA-FB-Raw | TXL AVG-3 samples | Wyoming PRB AVG-3 samples |
| Caculated | | | | | | | | |
| Cl DAF | 0.1418 | 0.0000 | 0.0000 | 0.0000 | 0.9096 | 0.4746 | 0.0199 | 0.0146 |
| VM-DAF | 0.7849 | 0.7670 | 0.7612 | 0.8620 | 0.8181 | 0.8089 | 0.4938 | 0.4634 |
| FC-DAF | 0.2151 | 0.2330 | 0.2388 | 0.1380 | 0.1819 | 0.1911 | 0.5062 | 0.5366 |
| VM-HHV,kJ/kg | 17130.18 | 16876.74 | 16302.33 | 18541.03 | 16000.19 | 18307.20 | 24045.91 | 25920.01 |
| VM-HHV,BTU/lb | 7365.98 | 7257.00 | 7010.00 | 7972.64 | 6880.08 | 7872.10 | 10339.74 | 11145.61 |
| VM-heat % | 65.60 | 62.90 | 61.33 | 77.94 | 68.72 | 70.28 | 41.72 | 40.59 |
| HHV (BTU/lb) | 1491.06 | 1834.38 | 2564.94 | 287.43 | 2710.49 | 5765.04 | 6143.33 | 7823.00 |
| HHV-as is-Boie, kJ/kg | 3787.44 | 4479.14 | 6297.23 | 746.94 | 7391.07 | 14684.36 | 14582.32 | 18347.96 |
| HHV-as is-Boie, BTU/lb | 1628.60 | 1926.03 | 2707.81 | 321.18 | 3178.16 | 6314.28 | 6270.40 | 7889.62 |
| HHV-DAF (kJ/kg) | 20493.91 | 20578.87 | 20233.96 | 20504.60 | 19049.44 | 21070.35 | 28459.80 | 29593.38 |
| HHV-DAF(BTU/lb) | 8812.38 | 8848.91 | 8700.60 | 8816.98 | 8191.26 | 9060.25 | 12237.72 | 12725.15 |
| Ash, kg/GJ | 6.17 | 7.64 | 22.00 | 51.31 | 74.72 | 12.01 | 8.02 | 3.10 |
| Ash,lb/mmBTU | 14.35 | 17.77 | 51.16 | 119.35 | 173.80 | 27.93 | 18.66 | 7.21 |
| CO2, kg/GJ | 99.23 | 98.27 | 99.83 | 101.42 | 101.10 | 93.89 | 95.37 | 93.71 |
| CO2, lb/mmBTU | 230.82 | 228.58 | 232.20 | 235.90 | 235.15 | 218.38 | 221.84 | 217.97 |
| N, kg/GJ | 1.04 | 1.20 | 1.54 | 2.39 | 2.47 | 1.85 | 0.48 | 0.36 |
| N, lb/mmBTU | 2.41 | 2.78 | 3.59 | 5.57 | 5.76 | 4.30 | 1.11 | 0.84 |
| S, kg/GJ | 0.1442 | 0.1172 | 0.2515 | 0.5984 | 0.5394 | 0.3953 | 0.4246 | 0.1502 |
| S, lb/mmBTU | 0.3354 | 0.2726 | 0.5849 | 1.3919 | 1.2546 | 0.9195 | 0.9877 | 0.3495 |
| NOx est, kg/GJ | 1.1939 | 1.3748 | 1.7737 | 2.7526 | 2.8461 | 2.1272 | 0.5474 | 0.4151 |
| NOx est, lb/mmBTU | 2.7771 | 3.1978 | 4.1256 | 6.4026 | 6.6199 | 4.9480 | 1.2732 | 0.9655 |
| SOx est, kg/GJ | 0.2884 | 0.2344 | 0.5029 | 1.1968 | 1.0788 | 0.7906 | 0.8493 | 0.3005 |
| SOx, est, lb/mmBTU | 0.6708 | 0.5452 | 1.1698 | 2.7838 | 2.5092 | 1.8390 | 1.9754 | 0.6989 |

| Empirical Chemical Formulae of Fuel | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Separated DB Solid | PC-DB 3-4 weeks Windrow | FCP-DB 3-4 month | Flushed DB | HA-FB-Raw | LA-FB-Raw | TXL AVG-3 samples | Wyoming PRB AVG-3 samples |
| Carbon | 0.7818 | 0.9525 | 1.3530 | 0.1540 | 1.4480 | 2.8601 | 3.0960 | 3.8737 |
| Chlorine | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0085 | 0.0085 | 0.0003 | 0.0003 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hydrogen | 0.9703 | 1.0792 | 1.4455 | 0.1683 | 2.0792 | 4.1287 | 2.1023 | 2.7030 |
| Nitrogen | 0.0257 | 0.0364 | 0.0657 | 0.0114 | 0.1113 | 0.1770 | 0.0485 | 0.0469 |
| Oxygen | 0.3838 | 0.4775 | 0.6688 | 0.0650 | 0.7313 | 1.3813 | 0.6004 | 0.7058 |
| Sulfur | 0.0016 | 0.0016 | 0.0047 | 0.0012 | 0.0106 | 0.0165 | 0.0189 | 0.0085 |
| Normalized Chemical Formulae of Fuel | | | | | | | | |
| Carbon | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| Chlorine | 0.0009 | 0.0000 | 0.0000 | 0.0000 | 0.0059 | 0.0030 | 0.0001 | 0.0001 |
| Hydrogen | 1.2410 | 1.1330 | 1.0684 | 1.0927 | 1.4360 | 1.4435 | 0.6790 | 0.6978 |
| Nitrogen | 0.0329 | 0.0382 | 0.0485 | 0.0741 | 0.0769 | 0.0619 | 0.0157 | 0.0121 |
| Oxygen | 0.4908 | 0.5013 | 0.4943 | 0.4220 | 0.5050 | 0.4829 | 0.1939 | 0.1822 |
| Sulfur | 0.0020 | 0.0016 | 0.0035 | 0.0081 | 0.0073 | 0.0058 | 0.0061 | 0.0022 |
| Mole Weight | 21.6717 | 21.7629 | 21.7880 | 21.1636 | 23.0607 | 22.3529 | 16.2175 | 15.8725 |
| Stoichiometric O2 and air( S to SO2, N to N2) | | | | | | | | |
| Stoich O2, kg/kg DAF fuel | 1.5753 | 1.5207 | 1.5031 | 1.6183 | 1.5456 | 1.6108 | 2.1289 | 2.1885 |
| Stoich O2, kg/kg as is | 0.2665 | 0.3152 | 0.4431 | 0.0528 | 0.5114 | 1.0250 | 1.0687 | 1.3454 |
| A:F, kg/kg DAF | 6.8490 | 6.6119 | 6.5352 | 7.0361 | 6.7198 | 7.0035 | 9.2559 | 9.5153 |
| A:F, kg/kg as is fuel | 1.1589 | 1.3706 | 1.9266 | 0.2294 | 2.2236 | 4.4563 | 4.6465 | 5.8497 |
| | | | | | | | | |
| Ash Elemental Analysis (%): (Ash was calcined @ 1100 deg. F (600 deg. C) prior to analysis) | | | | | | | | |
| Silicon, SiO2 | 35.13 | | | | 64.68 | 25.55 | 48.72 | 31.73 |
| Aluminum, Al2O3 | 6.02 | | | | 7.72 | 1.94 | 16.04 | 17.27 |
| Titanium, TiO2 | 0.21 | | | | 0.44 | 0.27 | 0.85 | 1.35 |
| Iron, Fe2O3 | 2.67 | | | | 2.90 | 1.37 | 7.44 | 4.61 |
| Calcium, CaO | 17.60 | | | | 7.09 | 20.20 | 11.70 | 22.2 |
| Magnesium, MgO | 6.12 | | | | 2.34 | 7.17 | 1.93 | 5.62 |
| Sodium, Na2O | 1.96 | | | | 1.38 | 4.94 | 0.29 | 1.43 |
| Potassium, K2O | 6.85 | | | | 4.50 | 12.70 | 0.61 | 0.67 |
| Phosphorus, P2O5 | 7.21 | | | | 2.81 | 11.11 | 0.10 | 0.8 |
| Sulfur, SO3 | 2.55 | | | | 1.06 | 4.46 | 10.80 | 10.4 |
| Chlorine, Cl | 0.32 | | | | 0.68 | 5.02 | <0.01 | <0.01 |
| Carbon dioxide, CO2 | 2.15 | | | | 1.35 | 1.71 | 0.08 | 0.37 |
| Total ash analysis | 88.79 | | | | 96.95 | 96.44 | 98.56 | 96.45 |
| | | | | | | | | |
| Metals in Ash, equal-weight-composite, mg/kg | | | | | | | | |
| Arsenic | | 8.5 | | | 4.12 | 3.96 | 24.7 | 17.6 |
| Barium | | 180 | | | 669 | 2620 | 1590 | 6230 |
| Cadmium | | 4.7 | | | <1 | 2 | 3.4 | 5.2 |
| Chromium | | 180 | | | <20 | 20 | 98 | 110 |
| Lead | | 10 | | | 20 | 20 | 47 | 130 |
| Mercury | | 0.06 | | | <0.01 | <0.01 | 0.01 | <.01 |
| Selenium | | <6 | | | <2 | 2 | <2 | <2 |
| Silver | | <4 | | | <2 | <2 | <2 | <2 |
| Total metals in ash | | 383.26 | | | 693.12 | 2667.96 | 1763.11 | 6492.8 |