Fluidized Bed Technology
Solution to Animal Waste Disposal

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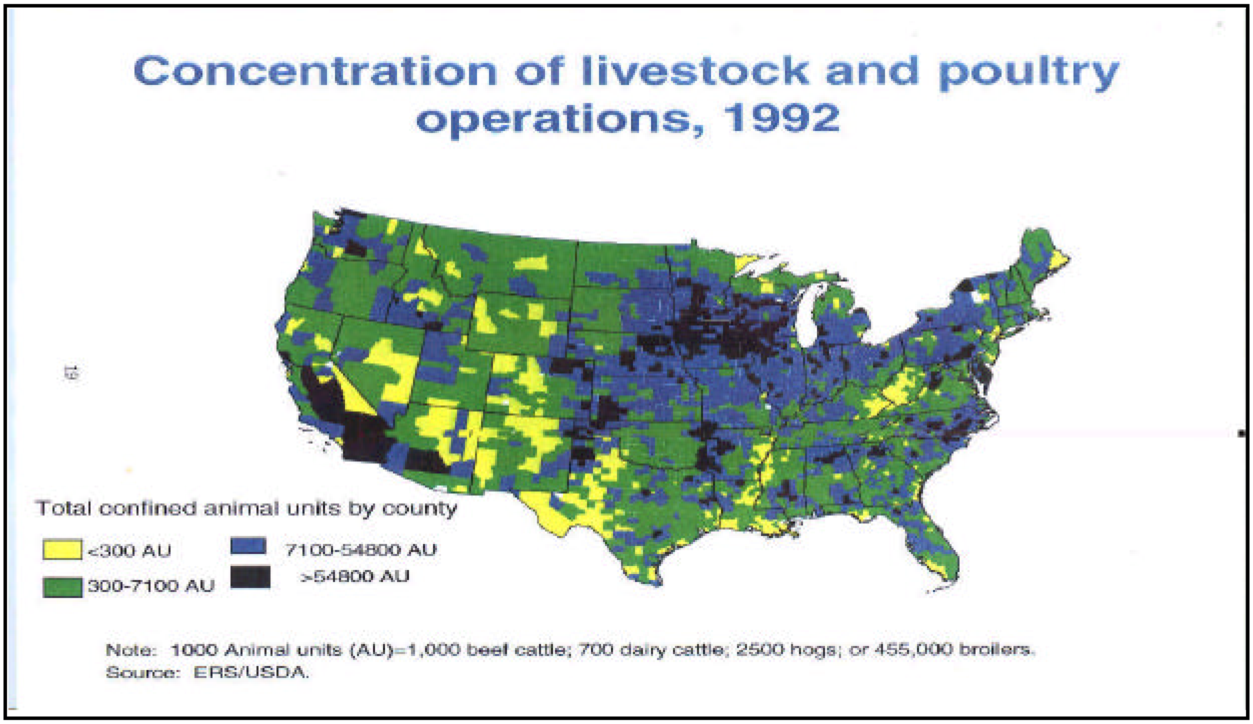
Our world is defined by two basic laws of physics which state simply that mass and energy cannot be created or destroyed, and that the overall state of chaos (disorder) within our universe is forever increasing. These two correlations are intimately interconnected. They might be better understood by the more common axiom, "You don't get something for nothing!"

An example of this relationship is the evolution of the modern, highly optimized agribusiness sector involving production of "healthy" meat supplies of both poultry (chicken and turkey) and pork. What was once a "cottage" industry has become an operation of enormous proportions, currently producing nearly 8 billion chickens, 300 million turkeys, 100 million hogs and 60 million cattle annually. In Virginia alone, the number of poultry farms has increased from 600 in 1990 to 1300 today, producing in excess of 260 million birds per year. In the same period, this state's production of chickens and turkeys increased by 68 percent and 75 percent, respectively. With high demand for these meat sources, there is no expectation of decline in these growth projections. As the production facilities expand, the amount and concentration of the wastes and specifically, manure, will also increase. It is estimated that the annual generation of wastes from the operation in Virginia alone accounts for about 2,250,000 tons. In the US, the solid wastes generated from poultry production is estimated at nearly 100 million dry tons per year. Hog production wastes account for an additional 110 million dry tons per year.

"You don't get something for nothing!" Because most of the producers have consolidated and/or established mega-facilities for raising much of the livestock and poultry today, the resultant wastes are likewise concentrated into these same areas. Although rich in nutrients and widely used as fertilizer, there is truth in the saying "too much of a good thing." Some studies indicate that where land application has been practiced for a number of years, the concentrations of nutrients, especially nitrogen and phosphorous, have exceeded acceptable levels. Surface runoff and groundwater leaching may have washed much of these excess nutrients into the local watershed, leading to significant pollution and damage to the ecosystem of those waterways. Once in the river basin, these added nutrients may have promoted increased plant and algae growth leading to increased oxygen demand in the water, eventually choking out the native forms of fish and other aquatic life.



Our insatiable appetite for the "healthy" meats has created industries which threaten to degrade the quality of life we are so anxious to enjoy. There are alternatives, and solutions, to this animal waste explosion by converting these wastes into usable energy in an environmentally clean manner. The waste streams created by these industries represent nearly 2,000 trillion Btu's of energy, roughly equivalent to 300 million barrels of oil. At $25 per barrel, this would represent an energy reserve equivalent to approximately $7.5 billion per year. Unfortunately, manure is not oil and the conversion from piles of barnyard waste to electrical power is not a simple step. However, a technology for energy recovery exists which has been proven over the past three decades which provides the means to recover much of the potential energy value from this waste and provide a much needed solution to the environmental degradation presently at hand.

Solution - Fluidized Bed Combustion with Energy Recovery

As with most waste materials, the disposal options run the spectrum of reduction, reuse, recycle, and finally, recovery. Reduction on a per capita basis is possible but given the continued growth of the industry is not likely to effect any major reduction in total waste generation. Reuse and recycling are effective but become cost prohibitive as hauling distances must be increased to avoid overburden of the local ecosystem. Recovery is typically in the form of energy production. One of the most effective methods of energy recovery utilizes fluidized bed combustion (FBC) and steam generation. Animal wastes consist of three primary constituents: water, organic matter, and inorganic matter.

More simply: water, fuel, and ash. Depending on the nature and source of bedding material and some housekeeping practices in the growing operation, the composition of the litter will range around 25 percent water, 60 percent fuel, and 15 percent ash. Combustion of this waste reduces the original weight as much as 85 percent prior to final disposal. Due to variations in densities of the material before and after combustion, actual volume reduction can be as much as 50 or 60 to 1. In other words, the actual quantity of waste to be disposed of after thermal treatment could be no more than 2 percent of the original volume. Such a reduction in volume could extend current landfill capacities by 50 times and allows for much greater flexibility for land application and soil enhancement practices by reducing transportation costs to a fraction of their current levels.

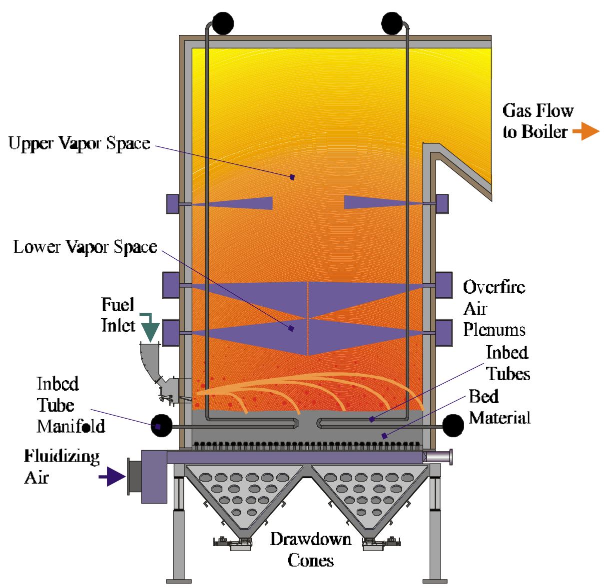


Figure 2
Typical Fluid Bed

Fluidized bed combustion technology has been in practice since the mid-1960s and has become the recognized "best available" technology for handling many of the non-standard solid fuel and/or waste materials currently being combusted. Technically the term fluidized, or fluid, bed is used to describe either circulating fluid beds (CFB) or bubbling fluid beds (BFB). The term is used to describe the fluid-like characteristics created in a container of sand-like particles when suspended by an upward flowing stream of air (Figure 2). As air introduced into the bottom of a bed of sand flows upward through the sand, it suspends the particles as the buoyant force of the air flow exceeds the weight of each individual particle. When the flow of air is further increased, the bed of sand begins to bubble, taking on the appearance of a pot of boiling water, hence the term "bubbling fluid bed." Further increase in the air flow will ultimately entrain the particles and elutriate them from the vessel. In a circulating fluid bed, these particles are captured from the gas stream exiting the vessel and are returned (recirculated) back into the vessel. In both BFB and CFB technology, incorporation of the fluid sand into the design greatly enhances the turbulence and mixing within the system and creates significant improvements to the combustion reactions.

With the Energy Products of Idaho (EPI) technology the bed media is comprised of a refractory sand material capable of withstanding very high temperatures without physical or chemical degradation.

The sand is coarse, yet uniform in size when first introduced into the system. A bed depth of approximately twenty to twenty-four inches is typical. Fluidizing, or primary, air is supplied to the base of this bed through a series of manifolds and air nozzles designed to uniformly distribute the air throughout the bed area. This primary air provides much of the combustion air required for the process. Additional air to complete combustion is introduced at various levels above the fluid bed as the gases travel through the remainder of the furnace. Typically, the entire chamber is lined with a refractory and insulation material to maintain a constant temperature zone for complete combustion and to achieve lowest possible emissions.

Under normal conditions, the combustor will operate at furnace temperatures of 1700-1800EF. The fuel is introduced into the system through appropriate fuel spreaders and comes in contact with the fluidized sand and air mixture. The sand provides a heat source to dry and automatically ignite the incoming fuel. Once ignited, the fuel releases energy back into the sand to maintain the operating temperature of the bed and sustain combustion in the system. Unlike other combustion processes, the thermal “flywheel” effect of the fluid bed provides a significant store of energy in the hot sand to drive off most of the fuel moisture content before igniting the remaining fuel. This allows the fluid bed to burn fuels significantly wetter and of poorer energy value than other combustion technologies. In certain applications, a portion of the steam generation capacity can be achieved through use of inbed and/or vapor tubes which remove energy directly from the furnace.

Another key advantage to fluid bed combustion is a direct result of the intense turbulence created within the bed. Most solid fuels, including coal, wood, and in particular the animal wastes, contain a substantial portion of noncombustible material which ultimately ends up as ash. In a “passive” combustion environment, typical of conventional grate technologies, this ash residue forms a coating over the fuel particle as it burns and actually impairs further combustion by restricting the accessability of oxygen to the particle surface. This phenomenon can be readily observed in the ash residue from a charcoal briquette fire or the wood ash remaining from a stove or campfire. Without any external enhancement, this ash layer grows around the fuel particle until it chokes out any further combustion. The turbulence of the fluid bed scours this layer of ash immediately from the surface of the particle resulting in a rapid and complete burnout of the fuel particle. Because the fuel is rapidly consumed, the inventory of fuel in the combustor at any given time is minimal. This feature further enhances the performance of the BFB by enabling it to follow load changes simply by varying the rate at which fuel is fed into the system.

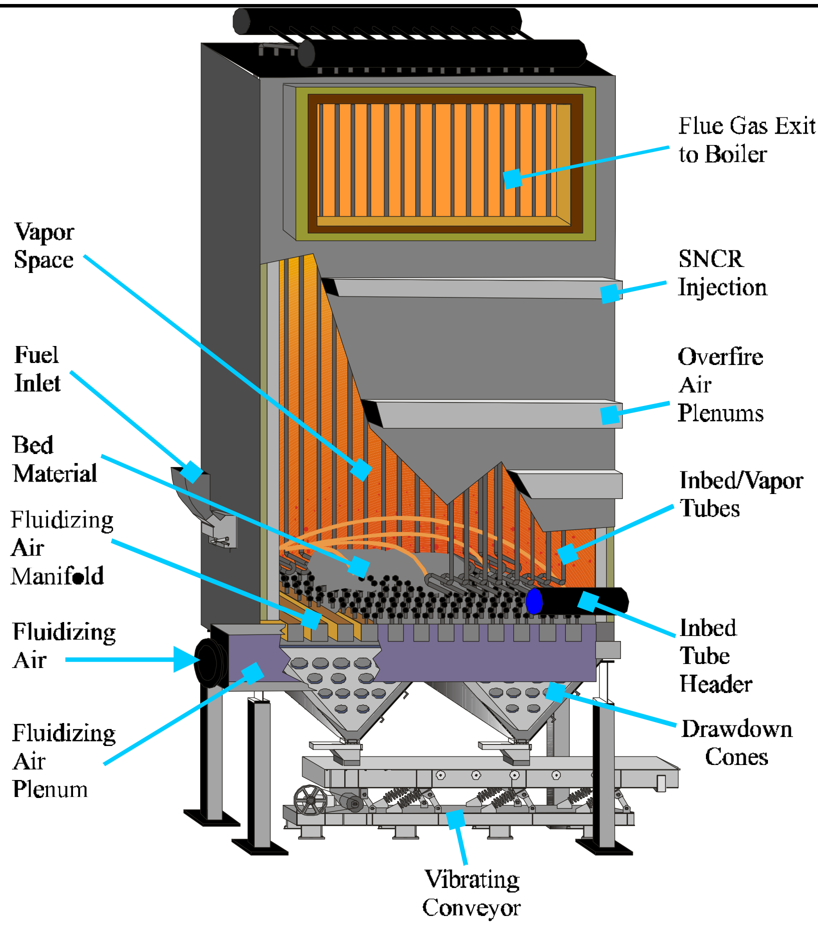


Figure 3
EPI Fluid Bed Combustor

Since 1973, EPI has applied this proprietary fluid bed technology to numerous energy recovery applications. Initial projects involved wood waste and biomass residues. Systems installed over the past two decades demonstrate the technology on such "uncommon" wastes as olive pits, wheat and rice straw, paper sludge, municipal wastes, and paunch manure, the stomach contents from a cow. In 1983 EPI explored the opportunities of utilizing poultry litter as a fuel source. At that time, EPI conducted a demonstration test utilizing 110 tons of rice hull-based poultry litter fired into an existing fluid bed boiler. EPI has continued to build its database and most recently again confirmed the viability of it's technology in a test program carried out at it's pilot test facility in cooperation with US Federal Energy Technology Center (FETC) representatives from the Pittsburgh laboratory.

Pilot Plant Test Facility

EPI maintains an operating pilot plant at it's headquarters in Coeur d'Alene, Idaho. The pilot plant includes a scaled-down fluidized bed combustor rated between 3 to 5 MBtu/hr, a fuel metering and delivery system, and flue gas cooling and cleanup equipment consistent with typical boiler and baghouse applications. The operation of the facility is computer automated with a data acquisition system capable of recording the significant process operating conditions on a minute-to-minute basis. The fluidized bed is preheated using a propane burner located above the active bed and via a direct propane injection nozzle in the active bed. In addition to developing an active data base of fuel combustion and feeding characteristics, the system is also equipped with the latest technology advances in selective noncatalytic reduction (SNCR) of nitrogen oxide (NO_X) emissions in the furnace through the use of ammonia injection and limestone injection into the bed for sulfur capture and other enhancements of the ash fouling characteristics.

The facility is equipped with continuous monitoring equipment for sulfur dioxide (SO_2), carbon monoxide (CO), oxygen (O_2), and NO_X, and can be tied in to additional external equipment for monitoring of other exhaust gases such as hydrogen chloride (HCl), volatile organic compounds (VOC's), dioxins, furans, and others. During normal operating campaigns, fuel and ash samples are taken periodically for additional lab analysis by a commercial testing firm.

EPI's test facility has been used since 1985 and has proven extremely accurate in predicting emission levels and other operating conditions for full scale plants. The fluid bed in this facility is 3' x 3', presenting a total bed area of nine square feet. The test results from this unit have been successfully scaled up to operating units of nine hundred square feet, literally one hundred times this size. Such an ability to accurately scale up the results of this test facility makes this unit invaluable in performing demonstration tests on new or unique fuel streams without incurring exorbitant costs or requiring extreme quantities of fuel. Most test programs require something less than a thousand pounds per hour of fuel. A complete environmental assessment and performance evaluation can be completed with less than twenty tons of fuel, equal to a single truck load.

Figure 4
EPI Test Facility

Poultry Litter Test Program

Poultry derived fuel (PDF) has never been considered for addition to any list of typical solid fuel sources. The earliest pioneers, traveling across the plains, were inclined to roast their meager provisions over a blazing pile of "buffalo chips" when firewood was scarce. Never, in any recorded journals of early frontier life, do we read about anyone stoking up the fire with another shovel full of chicken #*@**!!

The accompanying Table I presents the analysis of PDF waste and typical bituminous coal and wood wastes for comparison. PDF is typically one-fourth to one-half water with up to 25 percent of the balance being noncombustible ash. The PDF provided for this test is typical of material generated throughout the Delmarva (Delaware, Maryland, Virginia) poultry producing region.

Table I - Fuel Analysis

	PDF	Coal	Wood
Carbon, dry wt. %	39.5	74.0	49.7
Hydrogen, dry wt. %	4.3	5.1	5.4
Nitrogen, dry wt. %	3.9	1.6	0.2
Sulfur, dry wt. %	0.8	2.3	0.1
Ash, dry wt. %	22.9	9.1	5.3
Chlorine, dry wt. %	1.28	0.0	0.0
Oxygen, dry wt. %	27.3	7.9	39.3
Moisture, %	20-35	5.2	50
Dry HHV, Btu/lb	6572	13250	8800
LHV, Btu/lb as fired	3600-4400	12050	3315

By way of comparison, PDF is similar to typical wood waste in the relative percentage of carbon, hydrogen, and oxygen. The ash content is significantly higher in PDF due to the contaminants resulting from handling and co-mingling with dirt and wastes in the bedding operation. PDF and wood both have high volatile content ranging to 75 percent dry basis. Coal contains almost three times the heat content as either wood or PDF (LHV basis) and has a much lower moisture content, typically between 5 and 10 percent.

One of the most significant distinctions of the PDF analysis is the quantity and quality of ash present. This ash is characterized by the analysis presented in Table II.

Table II
Ash Mineral Analysis

	PDF	Aspen
SiO_2	26.7	6.47
Al_2O_3	2.9	0.72
TiO_2	0.19	0.06
Fe_2O_3	1.0	0.71
CaO	17.1	47.5
MgO	3.9	3.87
Na_2O	5.3	0.33
K_2O	14.4	7.38
P_2O_5	19.2	1.38

SO_3	**5.1**	**0.26**
Cl	**N/A**	**N/A**
CO_2	**4.2**	**32.19**

The above information shows that the poultry derived fuel is high in ash content at 23 percent and the ash is high in both potassium (K) and sodium (Na) oxides at 14 percent and 5.3 percent, respectively. Note the corresponding levels of K (7.38 percent) and Na (0.33 percent) in the aspen wood analysis which represents some of the highest levels of any wood ash. The high ash content plus the high levels of K and Na make the probability for ash fouling and/or slagging extremely high in the PDF material. Typically, the silica salts formed by potassium (K_2SiO_3) or sodium (Na_2SiO_3) exhibit strong tendencies to become sticky and form slag on the hot surfaces of the combustor and boiler. Continuous operation under normal furnace conditions will result in serious degradation of the boiler performance requiring shut down to wash, or chisel, the deposits from the affected surfaces. This can become a very costly problem in maintenance costs and loss of production from the facility. One of the primary objectives of the EPI test program was to evaluate this slagging tendency with EPI's technology and explore conditions which could reduce or eliminate it completely.

A second area of interest in the test program was an evaluation of the emission potential from this fuel. As with all fuels combusted in a fluidized bed boiler, the expected emissions from the combustion process are closely related to the quantities of precursers found in the fuel. For example, generation of NO_X from the process is directly related to the amount of nitrogen in the fuel. The same is true for SO_2 from fuel bound sulfur, and HCl from the chlorine in the fuel. In Table I, the analysis of PDF, coal, and wood show a relative comparison of the input levels of nitrogen, sulfur, chlorine, and ash. For better comparison, these levels should all be "standardized" to a common Btu basis, such as pounds per million Btu, to show a better direct comparison. This is presented in Table III.

Table III
<u>Comparitive Fuel Composition</u>

	PDF	**Coal**	**Wood**
Nitrogen	**6.0**	**1.21**	**.23**
Sulfur	**1.2**	**1.74**	**.11**
Chlorine	**1.94**	**0.0**	**0.0**
Ash	**34.8**	**6.9**	**6.02**
(Values in pounds per million Btu)			

From this comparison, it is readily apparent that PDF has significantly higher levels of nitrogen, chlorine and ash than the other fuels. Levels of sulfur were comparable to coal and ten times greater than wood. With this background, it was desired to measure the actual emissions to compare with other baseline studies and with potential emission requirements for a commercial facility.

The actual test program was conducted during August and September 1999. During the first few days of testing, basic operating parameters were evaluated as the fuel feed system was “customized” to handle the fuel. Originally it was anticipated that the material would be received in a size distribution nominally less than one half inch; however, the actual material exhibited a tendency to “clump” into sizing up to three inches, with a majority of clumps around one inch size. Due to this fuel characteristic it was possible to utilize a simple, overbed feed chute arrangement for the fuel feed, greatly simplifying the material handling requirements of the test.

Once the overall equipment configuration and control philosophy was confirmed, the system was operated at fairly steady state conditions for the next few days. The fuel and air ratios were established to maintain adequate operating velocities in the fluid bed as well as to control the temperatures in the bed and vapor at the desired levels. Typical operating temperatures out of the furnace were below 1750EF. The following data in Table IV summarizes most of the main operating conditions during the test. The high levels of oxygen were established as the initial setpoint for the test program until the other parameters could be ascertained. For a more efficient commercial design, this O_2 level would be reduced to around 6 percent through the use of appropriate design modifications within the fluid bed, including in-bed tubes and/or flue gas recirculation. Such enhancements would have no adverse effect on any of the emission parameters reported herein.

Table IV
Test Operating Conditions and Results

Test Date	9/17/99 3:00 pm	8/26/99 1:30 pm	9/17/99 1:30 pm
Fuel Feed rate, lb/hr	510	500	510
Energy input, MBtu/hr	2.285	2.123	2.285
Total air flow, lb/hr	5343	4445	4419
Vessel outlet Temp, EF	1541	1543	1574
Vessel Temp, EF (max.)	1644	1591	1696
Ca/S ratio for limestone feed	2.1	2.5	2.1
NH_3/NO_X ratio for SNCR	1.0	4.4	0
Flue Gas Emissions			
O_2, % dry vol	13	13	11.5
CO_2, % dry vol	6.7	7.5	8.2
NO_X, ppm (controlled/ uncontrolled)	25/225	20/90	225
SO_X, ppm	0	0	0

CO, ppm	**45**	**15**	**15**
HCl, ppm(controlled/ uncontrolled)	**12/78**	**not measured**	**47**

Observations - Slagging

As previously mentioned, ash slagging is a major concern for other technologies with combustion of the PDF due to the high levels of alkaline elements in the ash. Throughout the test program, the ash slagging effects were closely monitored. The system was inspected after every operating sequence to evaluate signs of ash buildup on the upper combustor and outlet dust walls. No significant ash slagging or accumulation was evidenced during the normal operating conditions at design temperatures. This was contrary to reports of severe slagging in other combustion technologies and was believed to be related to the unique fluidized bed operating conditions and lower operating temperatures established for these tests. To validate the slagging potential of this test fuel, the system was deliberately operated at furnace temperatures between 1800-2000E F for a one day run. Upon inspection, it was observed that measurable slagging and ash buildup occurred on the furnace walls over that brief operating period.

The test program was not conducted over a suitably long time period to fully evaluate the fouling potential, but the preliminary results were positive and did indicate that although the fuel was indeed capable of slagging and fouling, the normal operating conditions established during the tests did not promote fouling within the furnace.

Analyses of the various ash streams is being conducted to determine any intrinsic value of the material for soil supplement and to evaluate overall suitability for other disposal methods. Results of these analyses are not currently available and will be reported in future disclosures.

Emissions

The second objective of the testing was to obtain data on the primary emissions from the PDF combustion. Those are summarized in Table IV. Of significance here are the very low emissions of CO, SO_X, and NO_X. The low CO levels are consistent with all of the recent EPI fluid bed energy systems and came as no surprise. The SO_X and NO_X emissions, on the other hand, were substantially lower than anticipated. The projected emissions of SO_2 from the burning of the PDF, based upon the lab analysis, were around 500 ppm. The actual emission levels were zero. It has been proven that calcium in the fluid bed will capture much of the fuel bound sulfur and retain it as calcium sulfate ($CaSO_4$) in the ash stream. Throughout most of these tests limestone was added to the combustor at a Ca to S ratio of about 2 to1. In addition, the fuel ash has an inherent calcium content which brings to overall Ca/S ratio up to about 5 to 1. Achieving essentially 100 percent sulfur capture throughout all of the tests was considered a very positive result.

Much the same can be said of the NO_X levels. Based upon the fuel bound nitrogen content, which is the primary source of NO_X generation, the potential generation rate for NO_X is nearly 6000 ppm, or almost 20 pounds per million Btu input (lb/MBtu). Historically, the EPI fluid bed has resulted in NO_X generation levels somewhere between 10 and 20 percent of the potential nitrogen conversion level. In this case, however, the measured levels correlate to only fractional conversion of the fuel bound nitrogen. In a fuel having such high nitrogen levels, this low production rate of NO_X represents something of an anomaly. Preliminary research into other NO_X emission data from EPI facilities suggests that the low conversion rates of fuel bound nitrogen to NO_X can be attributed to high levels of fuel bound nitrogen existing as soluble ammonia or urea-based compounds. With so much of the fuel-bound nitrogen in the form of ammonia or urea it is likely abating NO_X rather than creating more.

As described earlier, the test facility is equipped with EPI's SNCR technology incorporating ammonia injection nozzles in the upper vapor region of the combustor. In these tests, anhydrous ammonia was evaluated. The result was an 89 percent reduction to an outlet NO_X level of only 25 ppm, equivalent to 0.08 lb/MBtu.

Of greatest concern among all the potential emissions is the chloride, or HCl, level. The PDF is quite high in chlorine content as already indicated, and the potential chloride emission levels were estimated at 750 ppm. Unlike the other acid gas, SO_2, the chloride emissions are not abated by any additional lime or limestone in the furnace because the temperatures exceed the equilibrium limits for calcium chloride compounds. Once temperatures fall below 1100EF, the calcium chloride salt is stable and is removed as particulate. Most HCl capture occurs in the spray dryer/dry scrubber system at the back end of the boiler train, where temperatures have been reduced below 400EF. In these tests, the HCl levels were measured downstream of the combustor, both ahead of and behind the baghouse. A baseline level was established without limestone addition and a second analysis was completed with limestone. The baseline tests indicated only about 10 percent of the potential chloride was released as HCl, and, after addition of limestone, these levels were reduced by about 40 percent. Addition of ammonia along with the limestone reduced the HCl levels further, equating to a capture efficiency of about 84 percent. These tests were conducted to provide some indications of the potential control efficiency of HCl emissions but were not intended to provide exact performance criteria. A more specific flue gas cleaning system is necessary to provide optimal performance for this type of cleanup; however, the tests did indicate a very positive ability to achieve significant chloride reduction using some very basic design modifications.

The Solution to Pollution

The results of the test program demonstrate the ability to combust the PDF material in a fluidized bed furnace and establish the technical viability of designing and operating a fluid bed boiler system to recover the energy from the poultry waste while meeting stringent air emission requirements. Scaling the test results to a design basis for a power generating facility results in the following criteria:

1) Design Basis - steam production - 200,000 pounds per hour
2) Projected "net" power generation capacity - 18,000 kilowatts
3) Required fuel (PDF) feed rate - 21.4 dry tons per hour

Using the initial projections of the quantity of poultry processing waste generated each year (100 million dry tons) and assuming an annual operating period of approximately 300 days per year, it is projected that there is sufficient PDF waste to build 650 power plants of this approximate size, with an overall net generating capacity of 12,000 MWe.

To put this into a different perspective, the fuel required to power a typical twenty megawatt facility as described herein would approach 150,000-200,000 dry tons per year. Referring to some of the published information indicating roughly one-tenth of a pound of dry manure per bird per day, the

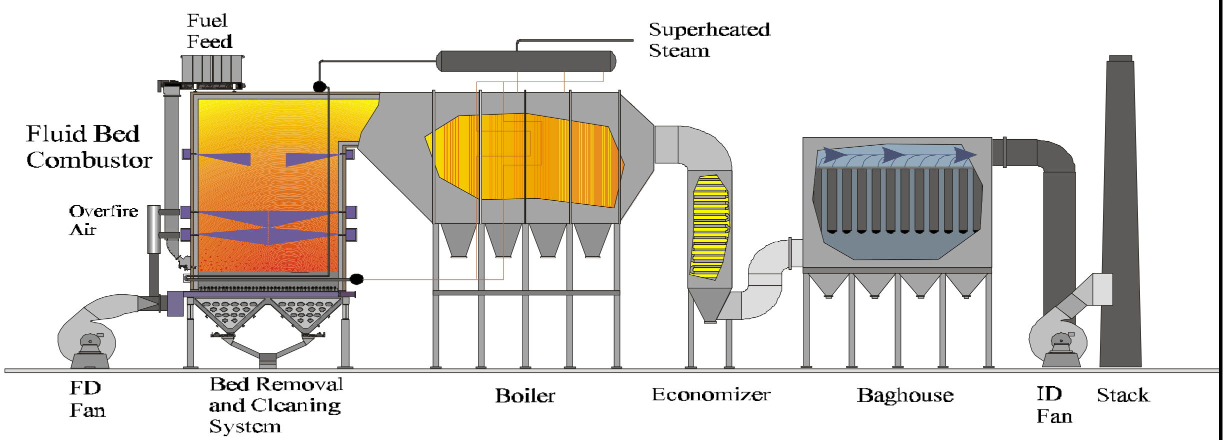


Figure 5
Typical Power Boiler System Schematic

above "fuel" requirement would be supplied by a poultry operation having an annual capacity of 11 million birds per year.

The overall economics of a waste-to-energy system utilizing PDF are very dependent upon the size and design of the system. Obviously, a completely new power generation station, including boiler, steam turbine generator, fuel management system, and all the necessary ancilliary equipment top the list of most expensive options for any given throughput capacity. A more simplified and economical option is to provide process steam or even turbine quality steam without incorporating a new turbine island. This is shown in the accompanying schematic diagram presented in Figure 5.

Retrofit of existing power stations or replacement of existing process steam supplies are candidates for this approach. Eliminating the power generation portion of the facility can result in capital cost savings of 50 percent or more. A third option is to retrofit an existing boiler with fluid bed technology, either by combustion or gasification. In gasification, the PDF is heated and volatilized, with only a portion of the fuel actually combusted to generate the necessary heat. The produced gases, rich in methane, hydrogen and carbon monoxide, plus other combustible gases, are fired directly into an existing furnace. This basic concept has been demonstrated by EPI on a number of applications and has the distinct advantage of requiring the least amount of capital equipment investment, provided the existing equipment design is suitable for such a retrofit.

Conclusion

The conclusion is simple and clear. Poultry and other animal wastes represent a formidable risk to groundwater and waterway pollution yet present an extensive supply of combustible fuel for production of energy. Utilization of fluidized bed technology is an efficient and environmentally friendly means of disposing of the waste material and recovering much of the energy value. Results from recent combustion tests on this material demonstrated that good combustion efficiencies and excellent emission levels can be achieved by properly designed and controlled fluid bed combustion technology. Waste-to-energy technology is an attractive option for dealing with this animal waste disposal issue.

EPI continues to maintain a proactive development program on this and other animal waste issues, both for combustion and gasification. Further testing is anticipated to evaluate the combustion parameters and environmental impacts from hog wastes and other animal waste streams.

Combined with an ongoing operation utilizing paunch manure, this continuing development effort will expand EPI's database on material handling and storage issues as well as combustion, gasification, and environmental parameters. Reports of these future development efforts will be made available as appropriate.