McDermott Technology, Inc.
a McDermott company

NEW SOLID FUELS FROM COAL AND BIOMASS WASTE

Final Report

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ABSTRACT

Under DOE sponsorship, McDermott Technology, Inc. (MTI), Babcock & Wilcox Company (B&W), and Minergy Corporation developed and evaluated a sludge derived fuel (SDF) made from sewage sludge. Our approach is to dry and agglomerate the sludge, combine it with a fluxing agent, if necessary, and co-fire the resulting fuel with coal in a cyclone boiler to recover the energy and to vitrify mineral matter into a non-leachable product. This product can then be used in the construction industry.

A literature search showed that there is significant variability of the sludge fuel properties from a given wastewater plant (seasonal and/or day-to-day changes) or from different wastewater plants. A large sewage sludge sample (30 tons) from a municipal wastewater treatment facility was collected, dried, pelletized and successfully co-fired with coal in a cyclone-equipped pilot. Several sludge particle size distributions were tested. Finer sludge particle size distributions, similar to the standard B&W size distribution for sub-bituminous coal, showed the best combustion and slagging performance. Up to 74.6% and 78.9% sludge was successfully co-fired with pulverized coal and with natural gas, respectively.

An economic evaluation on a 25-MW power plant showed the viability of co-firing the optimum SDF in a power generation application. The return on equity was 22 to 31%, adequate to attract investors and allow a full-scale project to proceed. Additional market research and engineering will be required to verify the economic assumptions. Areas to focus on are: plant detail design and detail capital cost estimates, market research into possible project locations, sludge availability at the proposed project locations, market research into electric energy sales and renewable energy sales opportunities at the proposed project location.

As a result of this program, wastes that are currently not being used and considered an environmental problem will be processed into a renewable fuel. These fuels will be converted to energy while reducing CO_2 emissions from power generating boilers and mitigating global warming concerns. This report describes the sludge analysis, solid fuel preparation and production, combustion performance, environmental emissions and required equipment.

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1.0 EXECUTIVE SUMMARY

1.1 Introduction

In response to DOE's "Solid Fuels and Feedstocks Grand Challenge", McDermott Technology, Inc. (MTI), (the R&D affiliate of B&W), and Minergy Corporation developed a project to evaluate sludge derived fuel (SDF) produced from sewage sludge. Our approach is to dry and agglomerate the sludge, combine it with a fluxing agent, if necessary, and coal, and burn the resulting fuel in the cyclone boiler to recover the energy and to vitrify mineral matter into a non-leachable product. This product can then be used in the construction industry. As a result of this program, wastes that are currently not being used and considered an environmental problem will be processed into a renewable fuel. These fuels will be converted to energy while reducing CO_2 emissions from power generating boilers and mitigating global warming concerns. Phase I of the project consisted of the laboratory scale development and testing of the technology. Phase II was intended to be for the proof-of-concept testing of the technology, however, MTI elected not to pursue funding. This report covers all Phase I activities.

1.2 Results

Phase I consisted of a feedstock preparation effort followed by pilot-scale combustion evaluation of promising SDF formulations and an economic study. A large sewage sludge sample (30 tons) from a municipal wastewater treatment facility was collected. The fuel properties of sewage sludge were characterized. The moisture level of the raw sludge was, as expected, very high (78%). On a dry basis, the sludge had 8346 Btu/lb and 36% ash, illustrating the available energy that could be recovered, along with a high amount of ash that will be converted to slag. Slag viscosity was measured for the melted slag showing that flux is not necessary for cyclone tapping. The high volatile matter content of 56.5% and nitrogen level of 3.2% showed the potential for high NO_x levels under normal combustion conditions and a need for investigating the combustion performance under reducing conditions via air staging technology.

A literature search showed that there is significant variability of the sludge fuel properties from a given wastewater plant (seasonal and/or day-to-day changes) or from different wastewater plants. Major human health effects of sewage sludge involve skin and eye irritation if the materials make contact with the eyes or skin. There were no carcinogens (per OSHA, IARC, NTP) in the sewage sludge tested. The sludge was classified as natural organic fertilizer. The trace metals and volatile organics can be detected in the dried sewage sludge in quantities less than 0.1%. The concentration of Hg could be of concern dependent on sludge variability and regulated levels.

The potential for producing a pelletized or compacted fuel from sewage sludge was explored. Initially, the sludge was dried from 78% moisture to approximately 1.5% moisture using an indirect/oil-heated disc-type dryer. This type of dryer produced a fine product (mostly finer than 40 mesh). Agglomerating options were reviewed to produce SDF and to produce different particle size distributions for testing in a cyclone-equipped pilot boiler. A sample of dried sludge was shipped to Midland Research for agglomeration testing. Midland Research used a briquetting technique to develop a ½-inch agglomerated fuel. Crushers were used to reduce the agglomerated fuel to the desired size for cyclone furnace optimization testing. In addition, an indirect/steam tube rotary dryer and a fluidized bed dryer were used to produce agglomerated fuel by drying alone and without the use of other processes such as briquetting. The dried material was stored in MTI's Small Boiler Simulator facility in 55-gallon containers for six months and absorbed very little moisture.

MTI's 6-million Btu/hr SBS was utilized to perform the pilot-scale study. The facility, that is equipped with an 18-inch cyclone furnace, simulates the gas side of full-scale boiler operation. This facility had been permitted to burn coal and gas, and we contacted EPA and obtained a permit to burn SDF in the facility. SBS combustion tests were carried out at a nominal load of 5-million Btu/hr. SDF and coal or natural gas were co-fired. The tested coal was a Powder River Basin (PRB) seam coal. The key parameters for investigation were the sludge feed rate, SDF preparation process (resulting in sludge particle size and moisture content), co-firing fuel (natural gas and coal), cyclone stoichiometric ratio and secondary air temperature.

The combustion of sludge was generally stable and showed good performance compared to numerous coals and a paper mill sludge that have been previously tested in the SBS. The cyclone was hot, and slag was tapping from the cyclone and bottom tap.

An economic evaluation on a 25-MW power plant was performed to determine the viability of firing/co-firing the optimum SDF in a power generation application. The estimated capital construction cost was $1600 per kilowatt resulting in a $40 million total construction cost. Based on the results of the pilot-scale testing and the co-firing of 50% (of the heat input) from coal, the remaining 50% of the heat input from the biomass was assumed for the full-scale boiler. The study showed that return on equities ranged from 22% to 31%. Major sensitivities were coal co-fire rates, processing fees for the biomass material and electric sales price.

1.3 Conclusions and Recommendations

The following conclusions and recommendations were derived:

- SDF can be produced by partially drying and pelletizing of sewage sludge.
- Sewage sludge, when properly dried and sized, can be successfully co-fired with natural gas and coal in a B&W cyclone boiler.
- Finer particle size distributions, similar to the standard B&W size distribution for sub-bituminous coal, showed the best combustion and slagging performance.
- Short-term (one to two hours) tests showed that sludge dried to10% moisture performed similarly to sludge dried to 2% moisture (slag tapping did not change).
- Up to 74.6% and 78.9% sludge were successfully co-fired with pulverized coal and natural gas, respectively.

- Increasing the secondary air temperature from 800°F to 900°F improved slag tapping (judging by visual observation).

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- NO_x emission levels decreased, as expected, with cyclone stoichiometry. The uncontrolled NO_x emissions at the maximum sludge input were 1300 - 1400 ppm. NO_x emissions decreased to 460 - 625 ppm at a cyclone stoichiometry of 0.95 - 0.99. SCR or SNCR can be used to reduce NO_x emissions to the compliance level.

- Firing the sewage sludge produced 1087 ppm and 1320 ppm SO_2 emissions for natural gas and coal firing with 78.9% and 74.6% sludge heat input, respectively. The technology would need a scrubber for reducing the SO_2 emissions.

- VOC and CO emissions were very low (less than 0.5 ppm and 50 ppm, respectively) during the optimum conditions of coal and sludge co-firing. CO emission was very sensitive to sludge feed rate fluctuations.

- The mercury concentration in the stack was high (144×10^{-6} grams/ Nm^3) due to the high mercury concentration of the sludge (1.0 ppm). However, a high percentage (76.7%) of mercury was oxidized which was attributed to a chlorine level of 0.21% in the sludge. A scrubber should be able to reduce the mercury concentrations.

- Based on the assumptions used, return on equities ranged from 22% to 31%. Major sensitivities are coal co-fire rates, processing fees for the biomass material, and electric sales price. The return on equity should be adequate to attract investors and allow the project to proceed.

- Significant variability exists between the sludge fuel properties from a given wastewater plant (seasonal and/or day-to-day changes) or from different wastewater plants. This is an important boiler design consideration and suggests that site-specific laboratory and bench-scale testing must be performed in order to determine its potential for firing in a cyclone boiler.

- Additional market research and engineering will be required to verify the economic assumptions to the degree required by investors. Areas to focus on are:

  1) Plant detail design and detail capital cost estimates.
  2) Market research into possible project locations and biosolids availability at the proposed project locations.
  3) Market research into electric energy sales and renewable energy sales opportunities at the proposed project location.

The project Phase II scope originally entailed full-scale demonstration of SDF usage in an existing or new cyclone boiler. At the conclusion of Phase I, it was decided that minimal fuel processing is required to burn the sludge in a B&W cyclone boiler. It was decided against pursuing funding for Phase II of the project under the DOE's "Solid Fuels and Feedstocks Grand Challenge". Minergy is pursuing a commercial project to commercialize the technology.

2.0 INTRODUCTION

The key to our Nation's strong, stable, and secure economic prosperity is available, reasonably-priced energy. To maintain economic competitiveness and meet its growing energy demand, the U.S. must improve the utilization efficiency of its domestic resources. Our vast resources of coal will play a strategic role in electric power production. Very important will be the utilization of non-fossil resources such as biomass and waste materials which, when co-fired with coal, will extend its expected life as an energy resource. Coal is currently estimated to provide a 200-year supply of cheap domestic energy at current production rates.

The expanded use of coal and waste materials must be done in an environmentally responsible manner. There is a very high priority on making energy available with minimal impact on the environment. Continued domestic growth in energy use coupled with dramatic growth in developing countries, one which will dwarf the growth anticipated domestically, is a global issue. Increased environmental emissions such as greenhouse gases must be addressed as effectively as possible.

With the results of the Kyoto Conference in December 1997, the emphasis on climate change issues has escalated. The world's first binding international treaty to limit greenhouse gas emissions will have a major impact on the United States and other developed countries. To address greenhouse gas emissions reductions in line with the proposed treaty, the U.S. will need to take action on a number of different fronts. Scientific consensus seems to be that any measurable reductions in atmospheric CO_2 will require a combination of schemes which include improved energy efficiency, energy conservation, and use of renewable fuels.

Interest is growing in the United States in the production of energy from waste materials. Sewage sludge is a readily available source of biomass, approximately 10 million tons/year(1), that can be utilized for its fuel value. Papermill sludge from production of paper products represents another 17 million tons/year of available sludge(2). However, the material can contain a wide variety of toxic substances, inorganic, organic, and biological. Available methods to dispose of the sludge include: incineration (which releases pollution into the air), landfill (which contaminates ground water), ocean dumping (where it has created vast underwater dead seas), and gasification (which is most expensive). Sewage sludge as a fertilizer, an existing use for this material, allows the accumulation of toxic materials in the food chain since they are recycled in the food we eat.

Thus, although sludges are an abundant renewable source of waste, environmentally appealing cost-effective uses for them are rather limited. The basis of this project is to restructure the waste into a sludge derived fuel (SDF) and combust it in a cyclone-fired boiler. This addresses the biohazards associated with the material, since they are destroyed at combustion temperatures found in a cyclone. Cyclone firing of the SDF also addresses hazardous elements content. The cyclone produces a vitrified slag that captures the predominance of toxic elements. Once solidified, the slag locks toxic compounds out of the environment for extended periods. The slag also has many uses in the construction industry and can be sold as a useful byproduct. This method of utilizing the SDF also improves the economics of the process, since it is burned with coal (versus natural gas).

Our approach is to partially dry and pelletize the compacted sludges, combine them with a fluxing agent, if necessary, and coal and burn the mixed fuel in the cyclone boiler to recover the energy and to vitrify mineral matter to form a non-leachable slag. It is possible that it is not economical to pelletize coal and sludge together. In this case, the pelletized sludge will be co-fired in the cyclone. It is the overall process, sludge to steam/electricity, that is novel. It has the following attributes:

1. It processes the environmentally unfriendly components of the sludge as a result of the high temperatures of combustion and isolates toxic compounds in a useable vitrified slag,

2. It provides a positive impact on CO_2 emissions by virtue of using a renewable fuel, and

3. It disposes of a material that will otherwise continue to accumulate at great cost, causing ever increasing environmental problems.

Figure 2-1 presents the process.

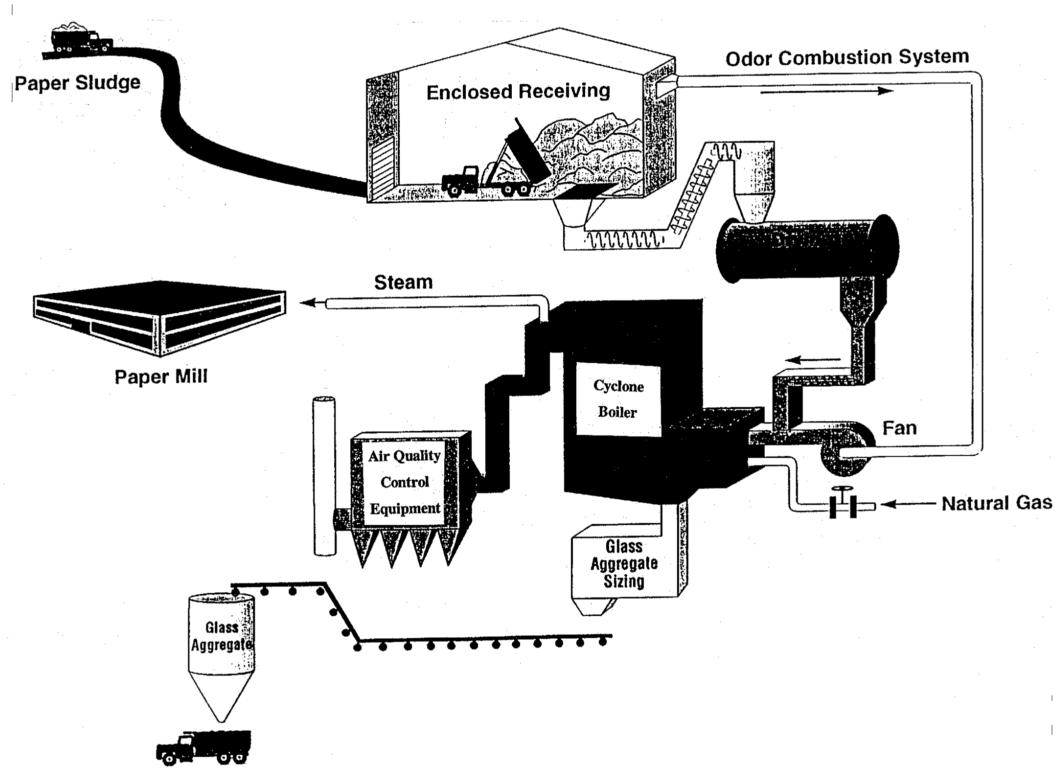

Figure 2-1. Schematic of Sludge Process Plant

The project was planned in two phases. Phase I consisted of a feedstock restructuring effort followed by pilot-scale combustion testing of promising SDF formulations. Phase II was planned to entail proof-of-concept-scale demonstration of SDF usage. However, this work was not pursued under DOE funding but is currently being developed using private-sector financing. Figure 2-2 shows a logic diagram for the project.

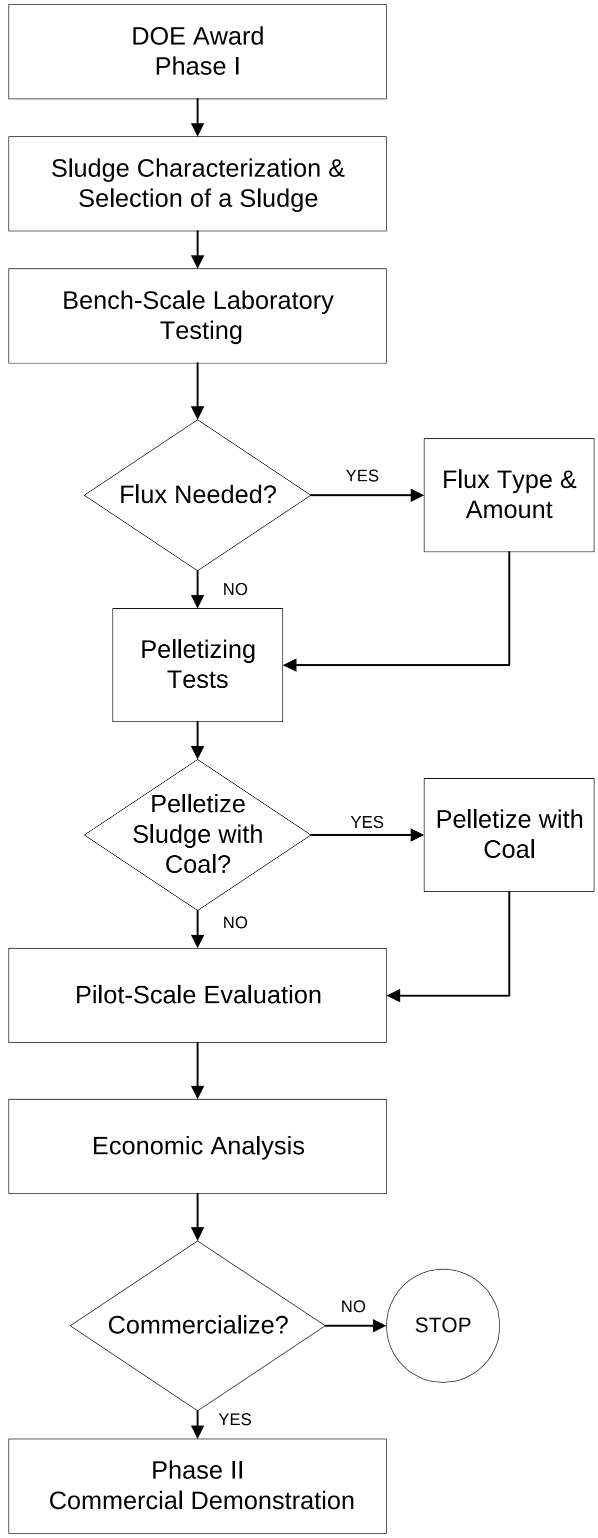

Figure 2-2. SDF Program Logic Diagram

Objectives of Phase I of this project are:

1. To characterize sludge and develop an SDF that can be co-fired with a fossil fuel such as coal or natural gas.

2. To evaluate the solid fuel for combustion performance in a cyclone-equipped pilot boiler, i.e., MTI's small boiler simulator. This will include characterization of slag samples from the cyclone to assure isolation of toxic materials as well as to identify potential uses of the slag in the construction industry.

3. To perform an economic evaluation of the technology. The concept must have demonstrated economic value in the power generation industry if it is to be widely accepted.

This report documents the result of Phase I. To accomplish the objectives of the project, a workscope consisting of five tasks is planned:

- Task 1: Sludge Characterization and Bench-Scale Testing
- Task 2: Sludge-Derived-Fuel Production
- Task 3: Pilot-Scale Testing
- Task 4: Economic Evaluation
- Task 5: Reporting and Project Management

3.0 RESULTS AND DISCUSSIONS

3.1 WBS Level 3 Task I.1: Sludge Characterization and Bench-Scale Testing

The objective of this task was to characterize the fuel properties of sewage sludge and to access its applicability to cyclone firing operation.

3.1.1 Subtask I.1.1: Sludge Characterization – A large sewage sludge sample from a municipal wastewater treatment facility was collected. The sample, as expected, had a moisture content of 78%. The proximate and ultimate analysis of the composite sample on a dry basis is shown in Table 3-1.

Table 3-1. Sewage Sludge Proximate and Ultimate Analyses

Proximate Analysis (%)	
Moisture	78
Fixed Carbon	1.1
Volatile Matter	12.4
Ash	7.95
Ultimate Analysis (%) – Dry Basis	
Carbon	42.64
Hydrogen	5.92
Nitrogen	3.16
Sulfur	0.820
Oxygen	11.34
Heating Value (Gross), Btu/lb Dry	8346

Most of the tests were performed with this sludge. During the tests several as-fired samples were analyzed to determine day-to-day variability (see Appendix A). Later on a smaller sample was taken from the same facility and additional tests were performed. Appendix A also shows the analysis on the second sample.

On a dry basis the large sample sludge has 8346 Btu/lb and 36% ash, illustrating the available energy that could be recovered, along with a high amount of ash that will be converted to slag. Of special importance is that the high volatile matter content of 56.5% and nitrogen level of 3.2% of the sludge would result in high NO_x emissions in a normal cyclone operation. Thus, we are considering a staged combustion mode for this fuel (see I.3.3). An ash mineral analysis was performed using the X-ray Florescence (XRF) method for determining the major metal oxide constituents (See Table 3-2).

We planned to use a Powder River Basin (PRB) coal for the tests. However, the first coal received and tested contained 1.65% sulfur and 12,360 Btu/lb indicating that the coal was not a PRB coal. A second coal was shipped to MTI which contained 20.95% moisture, 5.77% ash, and heat content of 9,503 Btu/lb. Appendix A shows the analyses of both coals.

Table 3-2. Sludge and Coal Ash Mineral Analyses

Metal Oxide	Sludge (%)	Coal (%)
SiO_2	34.5	34.0
Al_2O_3	14.6	10.8
CaO	10.8	22.5
MgO	4.0	3.2
Fe_2O_3	16.2	1.6
P_2O_5	15.9	1.1
TiO_2	1.4	1.6
K_2O	2.1	0.8
Na_2O	0.6	1.7
Total	100.1%	77.3%

The sludge and sub-bituminous coal ash mineral analyses show that both contain high levels of basic compound (e.g., CaO, MgO) an analysis similar to sub-bituminous coals. The high concentration of phosphorus could cause corrosion and or fouling problems in the convection pass. The analysis was also used in determination of slagging characteristics and the potential need for a flux (see Subtask I.1.2).

A major concern of combustion of sewage sludge is the variability of fuel from a given wastewater plant (seasonal and/or day-to-day changes) or from different wastewater plants. Table 3-3 shows the fuel variation from different plants in the Midwest and western United States. Significant variation exists between the Btu values and ash analysis. This is an important boiler design consideration and suggests that site-specific laboratory and bench-scale testing must be performed for each sludge in order to determine its potential for firing in a cyclone boiler.

Table 3-3. Variation of Sewage Sludge Fuel Properties from Different Wastewater Plants

Element (Dry Basis)	Mid West Plants			West Plants		
	A (%)	B (%)	C (%)	A (%)	B (%)	C (%)
Carbon	42.64	42.90	21.50	32.18	36.18	32.72
Hydrogen	5.92	6.30	3.11	4.60	5.71	4.59
Nitrogen	3.16	2.70	1.74	4.04	5.20	4.50
Sulfur	0.82	0.70	0.16	2.97	2.18	1.93
Oxygen	11.34	23.10	55.02	41.78	36.20	40.56
Ash	36.12	24.30	18.47	14.12	15.07	15.70
Heating Value, Gross (btu/lb dry)	8346	7949	3593	6280	6982	6184
	Mid West Plants			**West Plants**		
Metal Oxide	**A (%)**	**B (%)**	**C (%)**	**A (%)**	**B (%)**	**C (%)**
SiO_2	34.5	39.2	20.8	25.9	27.6	20.8
Al_2O_3	14.6	13.5	10.0	10.3	10.6	10.4
CaO	10.8	17.5	40.7	14.4	16.9	18.7
MgO	4.0	1.4	4.3	2.0	3.2	1.8
Fe_2O_3	16.2	6.2	11.1	24.6	15.7	22.3
P_2O_5	15.9	16.5	7.9	18.3	21.4	21.7
TiO_2	1.4	1.7	0.7	0.7	1.2	0.8
K_2O	2.1	1.4	1.0	1.0	0.8	0.8
Na_2O	0.6	1.3	1.0	1.7	1.1	1.1
TOTAL:	100.2%	98.6%	97.6%	98.8%	98.5%	98.4%

One concern about using sewage sludge is the heavy metal content. Table 3-4 shows the concentrations of metals in the sewage sludge as measured by standard EPA Methods. The impact of the metals should be reviewed on a site specific basis. It should be mentioned that a cyclone should vitrify a large portion of metals with high boiling points (like Chromium) in the slag.

Material health effects of sterilized sewage sludge are documented in Appendix B. Major human health effects involve skin and eye irritation if the materials make contact with the eyes or skin. There are no carcinogens (per OSHA, IARC, and NTP) in the sludge. The dried sludge is classified as natural organic fertilizer. The trace metals and volatile organics can be detected in the dried sewage sludge in quantities less than 0.1%. The concentration of Hg could be of concern dependent on sludge variability and regulated levels. For comparison, the heavy metals content from a typical PRB is shown in Table 3-4.

Table 3-4. Sewage Sludge Heavy Metals (on a dry basis)

Element	Sludge	Typical PRB Coal
Antimony	<1 ppm	---
Arsenic	5.8 ppm	5.62 ppm
Barium	69.0 ppm	---
Cadmium	8.1 ppm	0.148 ppm
Chromium	110.0 ppm	8.37 ppm
Cobalt	3.0 ppm	2.41 ppm
Lead	28.0 ppm	4.86 ppm
Manganese	53.0 ppm	49.54 ppm
Nickel	21.0 ppm	6.81 ppm
Selenium	8.2 ppm	1.26 ppm
Mercury	0.080 ppm	0.105 ppm
Zinc	300.0 ppm	---

3.1.2 Subtask I.1.2: SDF Chemical Formulation – The chemical data was analyzed for compatibility to cyclone boiler operation. The metal oxide analysis was reviewed for its glass making properties. The calculated temperature at which the slag has a viscosity of 250 poise (T250) is well within cyclone capability. Although, our calculations showed that fluxing probably is not needed on this sample of sludge, these calculations are based on a database of coal ashes, and there is potential for error when it is extrapolated to sludge ash. The measured slag viscosity is shown in Figure 3-1. The measured T250 is 2300^{o}F for the melted slag showing that flux is not necessary for normal coal firing applications.

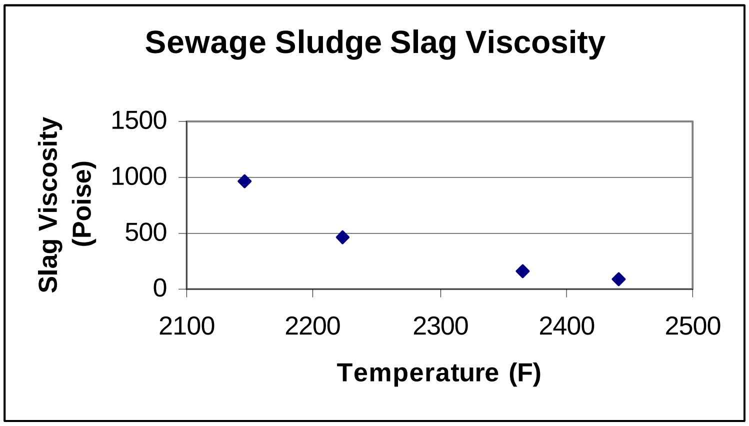

Figure 3-1. Slag Viscosity

However, we performed flux tests of the sludge ash in order to lower T250 (and maximize total heat input by the sludge). Limestone and cullet (a by-product of the glass industry) were selected as fluxing materials. The measured viscosity tests with 10% cullet showed higher slag viscosities than the slag viscosity for sludge alone. We decided to proceed with the pilot tests assuming that we will not flux the sludge. Depending upon the potential sludge variability, flux may be required in the commercial applications to consistently maintain acceptance slagging characteristics. Limestone or sand may be used as flux depending on the characteristics of the sludge.

3.2 <u>WBS Level 3 Task I.2: Sludge-Derived-Fuel Production</u>

The objective of this task was to characterize the sludge with respect to its potential for producing an agglomerated fuel. A large sample, approximately 30 tons, of sludge was taken by Minergy from a wastewater treatment plant and transported to a properly permitted drying facility. The sludge was dried using three different types of dryers from 78% moisture to approximately 1.5% moisture and was then shipped to MTI. The dried material was stored in the SBS facility in 55-gallon air sealed containers for six months and absorbed very little moisture (material tested contained up to 3% moisture).

Cyclones typically perform well when firing a good bituminous coal with a particle size distribution that is nominally as follows:

Size Mesh	% Less than
#4	90
#8	73
#16	52
#30	34
#50	21
#100	12
#200	7

Although this was our initial predicted sludge size distribution, optimization of sludge size was a key combustion parameter to maximize sludge utilization.

Minergy utilized three types of dryers to produce the feed material. The first type was an indirect/oil heated disc type dryer. No product back mixing was required with this arrangement. This type of dryer produced a fine product (mostly finer than 40 mesh) which requires mechanical compacting to obtain the required cyclone fuel sizing specification.

The second type of dryer used was an indirect/steam tube rotary dryer. This type of dryer requires back mixing. Back mixing is the process of recirculating a stream of dry material from the discharge of the dryer to mix with the wet infeed material. With the proper mixing rates and design and speed of the mixer, the mixture will form an agglomerated product that will hold up through the drying process. These materials were tested as base line conditions for suitability for cyclone testing. The third type of dryer used was a fluidized bed dryer that showed promise of a viable agglomerated fuel.

Other mechanical agglomerating options (versus dryers) were reviewed to determine the appropriate particle size distribution for cyclone boiler operation. A sample of the dried sludge was shipped to Midland Research for agglomeration testing. Midland Research used a briquetting technique to develop an agglomerated fuel. Midland Research produced 1/2" briquettes from the sludge. Figure 3-2 shows a photograph of the briquetted materials.

Figure 3-2. Sewage Sludge Briquettes

Appendix C contains letter reports explaining the processes for drying and briquetting of sludge. It is noted that the briquetting technology could produce very strong agglomerated materials if adequate water is added. We chose to add a moderate level of water to produce a fuel that could be easily crushed for cyclone operation. Crushers were used to reduce the agglomerated fuel to the desired size for cyclone furnace operation. The sludge size distribution was a key parameter to maximize sludge utilization (See Task 3).

As mentioned earlier, all this work was performed with a 30-ton sample of sludge. The dried material, produced by an indirect/steam tube rotary dryer, was relatively fine and contained 1.5% moisture. The material was stored in the SBS facility in 55-gallon air sealed containers for six months and absorbed very little moisture (material tested contained up to 3% moisture). However, economic considerations indicate that we needed to test sludge with a higher moisture (10%) level.

Minergy took a 10-ton sludge sample from the Detroit facility and attempted to dry the sludge to nominally 10% moisture. They used an oil-fired drier that dried most of the sludge to 2% moisture. Only three barrels were dried to 10% moisture, two barrels to approximately 5% moisture, and the remainder (20 barrels) was dried to 2% moisture. To achieve our objective we decided to increase the sludge moisture by spraying fine water on seven barrels of 2% moisture sludge.

We noticed some differences in some of the sludge. The sludge that was dried to 10% moisture had more fiber (judged by visual observation) and contained only 6510 Btu/lb (7296 Btu/lb, dried basis). The sludge that was moisturized from 2% to 10% was similar to the previous batch from Detroit and had a Btu value 7402 per pound (8267 Btu/lb, dried basis). This can be a result of drum to drum sludge variability. It is important to mention that the composite Btu value from the sludge provided by the customer was only 6081 Btu/lb on a dry basis.

The fibrous sludge was low in density and difficult to feed with the gravimetric belt feeder. We experienced non-uniform sludge feed with this low-Btu fibrous sludge. Fewer problems were experienced while feeding the moisturized sludge. This sludge contained 37.7% ash, 2.96% nitrogen, and 8267 Btu/lb (on a dry basis). Appendix A shows the sludge and coal analyses.

3.3 <u>WBS Level 3 Task I.3: Pilot-Scale Combustion Testing</u>

The purpose of this test is to demonstrate the co-firing of SDF and coal or other fossil fuels in a cyclone-equipped pilot. The data from combustion testing and the slag leachability tests will be used for the design and permitting of the planned proof-of-concept-scale demonstration. The main focus of the combustion tests was to determine the following parameters:

1. The maximum sludge feed rate to the cyclone while cyclone slagging is maintained.
2. The optimum sludge feed size and moisture level for proper cyclone operation (slagging).
3. The emission levels including NO_x, CO, SO_2, VOC, and mercury levels in the convection pass exit.

3.3.1 <u>Subtask I.3.1: Making SDF</u> – Midland Research produced two batches of sewage sludge briquettes that were crushed later for combustion testing. The two batches of the material were prepared using the same technique and produced similar SDF containing similar moisture (see below). Also dried agglomerated material was prepared by two technologies: a fluidized bed technology, and an indirect/steam tube rotary dryer. These processes produce an agglomerated fuel by drying alone and without the need of another technique such as briquetting. The materials were shipped to MTI. In addition, Minergy had already delivered to MTI a fine dried material using an indirect/oil heated disc type dryer. These three techniques produced three different size distributions that were tested in the cyclone pilot.

Figure 3-3 shows the particle size distribution of the three samples as well as the B&W standard coal firing size distributions. B&W recommends a finer feed for subbituminous coal for cyclone firing than for bituminous coals. The lower and upper lines are the recommended size distribution for bituminous and subbituminous coals. Processing the indirect/oil-heated, disc- type dryer produced a dry material (3.57% moisture as fired) similar to the B&W recommended size distributions for subbituminous coal. The two batches of briquetted/crushed material by Midland Research were coarser and contained 4.06 and 5.4% moisture. The dried and agglomerated material produced by an indirect/steam tube rotary dryer was much coarser and contained 6.37% moisture. We decided to screen the material through a 3/8" screen. Appendix A shows the analysis of sludge.

3.3.2 <u>Subtask I.3.2: Combustion Equipment Site Preparation</u> – MTI's 6-million Btu/hr Small Boiler Simulator (SBS) was utilized to perform the pilot-scale study (Figure 3-4). A short description of the facility pertinent to scale-up is presented here.

The SBS is fired by a single, scaled-down version of B&W's cyclone furnace. Coarse pulverized coal (50% through 200 mesh), carried by primary air, enters tangentially into the burner. Pulverized coal had to be utilized in the SBS instead of crushed coal to obtain complete combustion in this small cyclone. Preheated combustion air at 600° to 800°F enters tangentially into the cyclone furnace.

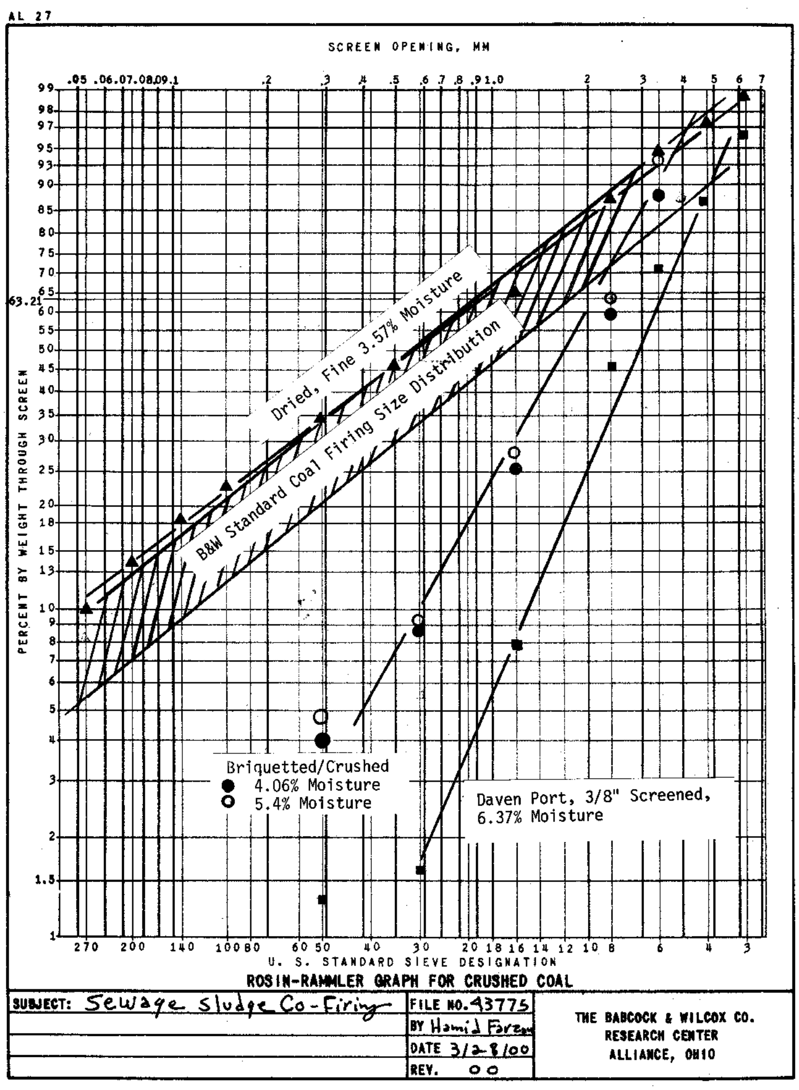

Figure 3-3. Sewage Sludge Particle Size Distributions

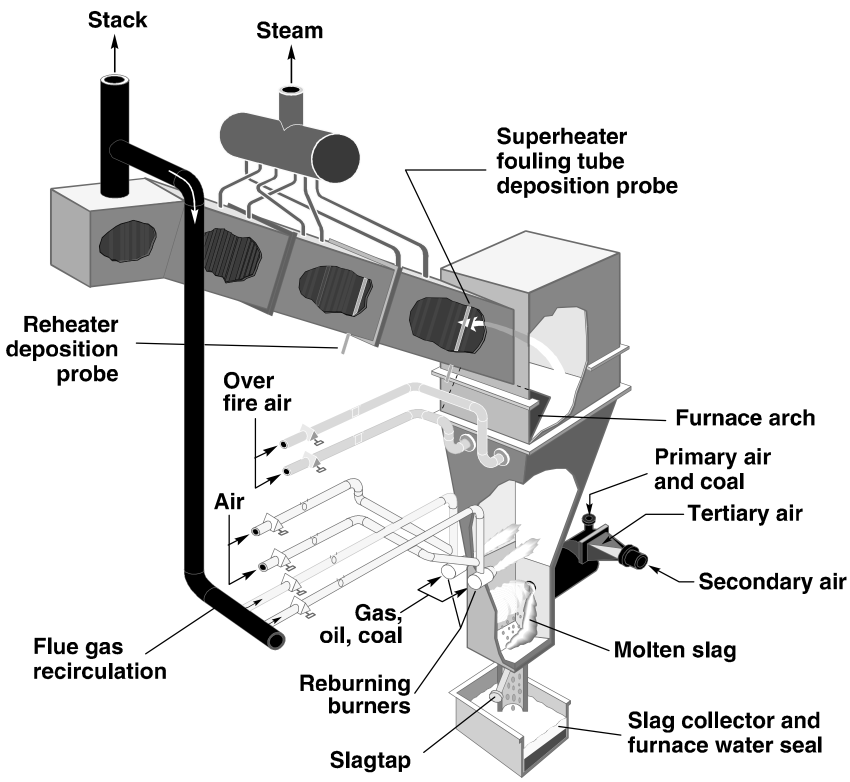

Figure 3-4. Small Boiler Simulator (SBS)

The water-cooled furnace simulates the geometry of B&W's single-cyclone, front-wall fired cyclone boilers. The inside surface of the furnace is insulated to yield a furnace exit gas temperature (FEGT) of 2250°F at the design heat input rate of 6-million Btu/hr. This facility simulates furnace/convective pass gas temperature profiles and residence times, NO_x levels, cyclone slagging potential, ash retention within the resulting slag, unburned carbon, and fly ash particle size of typical full-scale cyclone units. A comparison of baseline conditions of these units is shown in Table 3-5.

Table 3-5. Comparison of Baseline Conditions for the SBS Facility and Commercial Units

Typical Cyclone	SBS	Boilers
Cyclone Temperature	3000^oF	3000^oF
Residence Time	1.4 seconds*	0.7 - 2 seconds
Furnace Exit Gas Temperature	2265^oF	$2200^o – 2350^oF$
NO_x Level	700 – 1200 ppm	600 – 1400 ppm
Ash Retention	80 – 85%	60 – 80%
Unburned Carbon	<1% ash	1 – 20%
Ash Particle Size (MMD: Bahco)	6 – 8 microns	6 – 11 microns
* At full load		

Two reburning burners can be installed on the SBS furnace rear wall above the cyclone furnace for NO_x reduction (they were not in service for these tests). Each burner consists of two zones with the outer zone housing a set of spin vanes while the inner zone contains the reburning fuel injector. Air and flue gas recirculation (FGR) can be introduced through the outer zone. Overfire air (OFA) ports are located on both the front and rear walls of the SBS at three elevations, with each elevation containing two ports. The Rear OFA ports were used for air staging tests.

This facility had been permitted to burn coal and gas, and we contacted EPA and obtained a permit to burn SDF in the facility. The SBS is equipped with pulverized coal (PC) fired capability via a gravimetric belt feeder. This small cyclone uses coarse PC (50% less than 200 mesh) for combustion simulation. These feeders were not compatible with SDF due to size. For SDF firing, a sludge feed system was located close to the cyclone at an elevation higher than the cyclone. The SDF was fed into an aspirator and was introduced into the cyclone.

3.3.3 **<u>Subtask I.3.3: Combustion Testing</u>** – SBS combustion tests were carried out at a nominal load of 5-million Btu/hr. SDF and coal or natural gas was co-fired. The key parameter for investigation were as follows:

- Sludge feed rate to cyclone
- SDF preparation process (resulting in sludge particle size and moisture content)
- Co-firing fuel, natural gas and coal
- Cyclone stoichiometric ratio
- Secondary air temperature

The combustion of sludge was generally stable and showed good performance compared to numerous coals and a paper mill sludge that have been previously tested in the SBS. The cyclone was hot and slag was tapping from the cyclone and bottom tap. Combustion performance of the sludge was judged by visual observations of the burnout in the cyclone furnace and in the boiler (this will be discussed later in this section). Boiler operational data and stack gases (O_2, CO_2, CO, NO_x, and SO_2) were measured for all tests. Cyclone and lower furnace temperatures, fly ash concentrations at the convection pass outlet (before particulate clean-up equipment) were measured for selected tests. Volatile organic compounds (VOC) and mercury were measured at the boiler convection pass outlet at an optimum condition. A summary of all the tests performed during this project is shown in Appendix D.

3.3.4 Subtask I.3.4: Data Analysis, Evaluation, and Scaling – The data were plotted and analyzed as shown below.

Cyclone Combustion and Slagging Performance

The most critical factor in cyclone operation is slagging performance at the cyclone tap as well as the furnace bottom tap. The cyclone slagging is discussed versus the key parameters in this study.

Sludge Size Distributions – The sludge size distribution was varied as was explained in SDF formulation task. The effect of size distribution was examined in the pilot combustor unit. As explained before, one of the main variables used to evaluate combustion performance was by visual sludge and/or coal carry over into the primary furnace. The tests showed that within the three different feed sizes tested, the sludge with finer particle size distributions performed the best. Finer sludge, introduced through the secondary air, tends to stay in the cyclone and burn. Some particle carry over was observed, but the majority melted in the main furnace before it reached the bottom slag tap. When the briquetted and crushed material was used, sludge carry over to the main furnace increased, and some unburned particles entered the furnace slag tap. That is not desirable. Briquetted materials need to be crushed finer for optimum cyclone performance. Larger particle feed sizes from the drying process produced unacceptable cyclone performance judging from many unburned particles reaching the furnace tap. However, when the larger particles were screened, cyclone performance was improved.

Co-firing Fuel – Sludge was successfully co-fired with coal and natural gas. Co-firing with coal produced a more uniform combustion condition judging from the cyclone exit throat. The cyclone was hotter, and the cyclone slag tap was open. Slag was tapping from the bottom of the stag tap. Natural gas co-firing produced acceptable cyclone firing with the slag tap partially closed, and slag was tapping over the throat. Main furnace slag tapping was easier with natural gas than coal.

Sludge Feed Rate – Sludge heat input was increased from 13% to 85.7% while the total heat input was kept constant at 5-million Btu/hr and normal firing conditions under excess oxygen. The visual observations and slag tap measurements showed that the cyclone was hot, and slag was tapping out of the slag tap. Figure 3-5 shows that the slag tap temperature without any sludge input was 2400^{o}F to 2455^{o}F for all conditions (natural gas or coal). The slag temperature varied between 2300^{o}F and 2530^{o}F as the sludge heat input changed between 13.6% and 85.7%. Some sludge was also leaving the cyclone and was trapped on the primary furnace walls before it burned and the mineral matter melted into slag. The highest heat inputs while maintaining acceptable cyclone slagging performance were 78.9% and 74.6% co-firing with natural gas and coal, respectively. The highest sludge heat inputs by sludge were determined from the sludge carry over into the primary furnace.

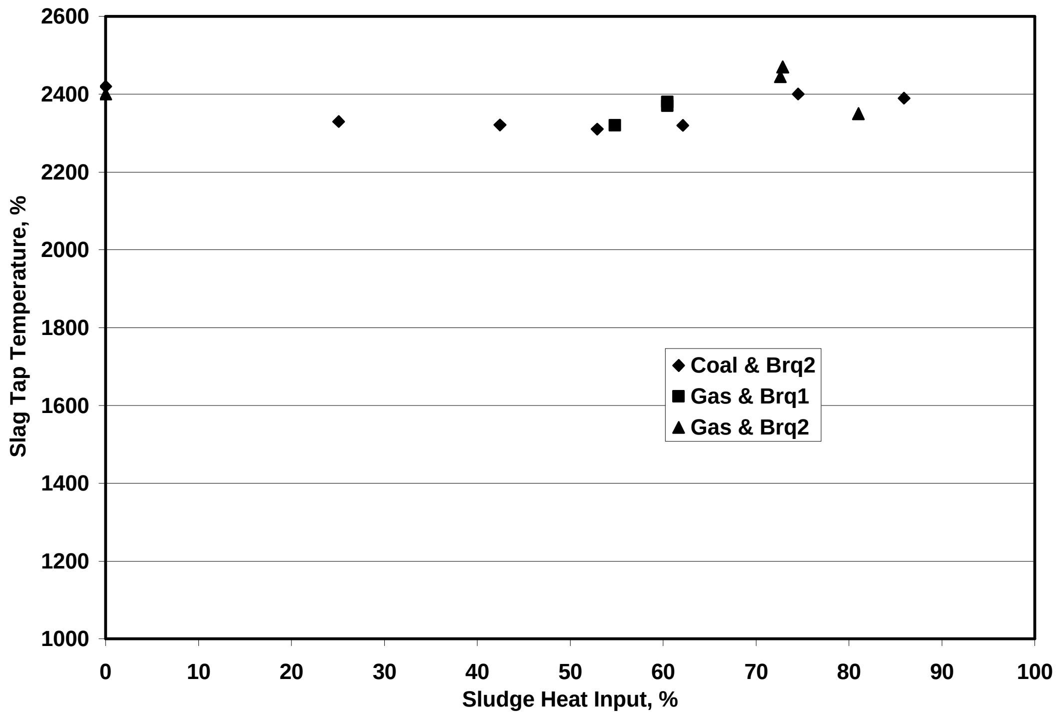

Figure 3-5. Uncontrolled Conditions Cyclone Slag Tap Temperature

Fly Ash Loading and Unburned Combustibles – Since the primary advantage of a cyclone combustor over other boilers is slag formation, we attempted to qualify the percentage of ash leaving the boiler. After optimum conditions were determined, fly ash loading was established to determine how much ash is leaving the convection pass outlet (and remainder as slag). Fly ash measurements showed that most of the ash melts into slag and a small fraction of ash (1.7% and 3% for natural gas and coal co-firing) was entrained in the combustion gases and captured by the baghouse. Slag from the sludge co-firing was solid and similar to slag from coal combustion. The unburned combustibles were low in the fly ash ranging from 0.4% to 1% for natural gas and coal co-firing under the optimum conditions. CO levels were also low, ranging from 13 to 45 ppm. CO levels occasionally increased when the sludge feed was not uniform. Overall, the conclusion is that due to the high volatile matter content of sewage sludge, very low levels of unburned combustibles were detected in the combustion gas at the convection pass outlet.

Cyclone Staging – Since sewage sludge contains high levels of nitrogen, the uncontrolled NO_x levels are high. Air staging was considered as the combustion modification technology to partially reduce NO_x. The effect of staging on cyclone performance is discussed here, and NO_x results will be discussed later. Figure 3-6 shows the cyclone temperature as a function of cyclone stoichiometry for coal and gas co-firing for all tests. The data shows that the cyclone temperature varies with the cyclone stoichiometry in the range tested. Direct comparison of staged and uncontrolled data on the same day for coal firing shows that the slag tap was 80°F higher under the staged conditions. Overall cyclone operation was satisfactory in all conditions.

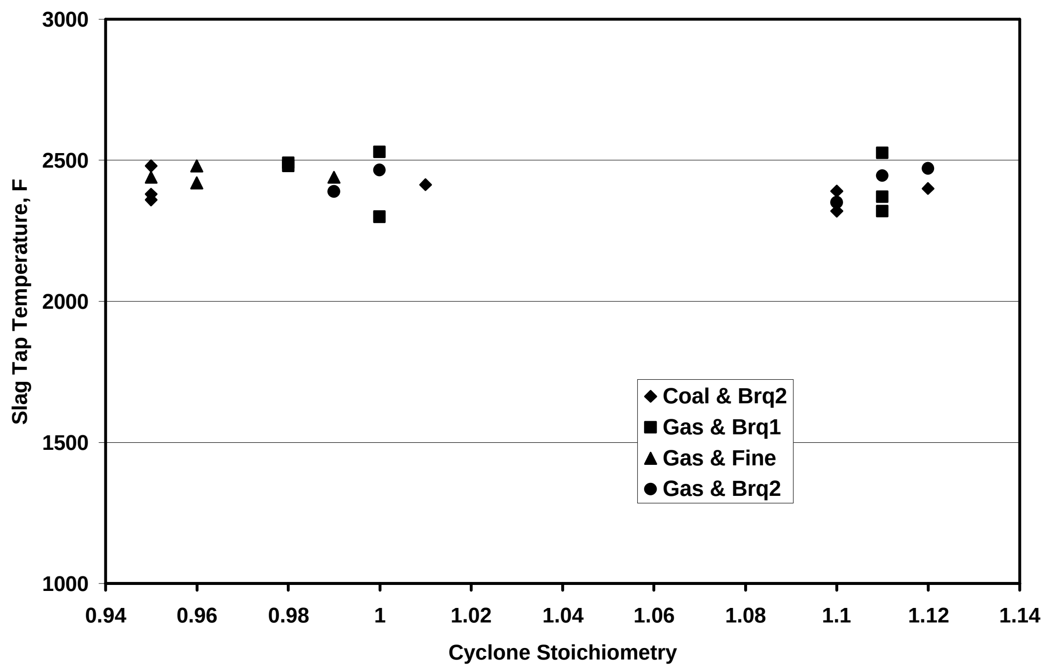

Figure 3-6. Staged Conditions Cyclone Slag Tap Temperature

Secondary Air Temperature – The effect of secondary air temperature was evaluated on the slagging conditions. We judged the performance by cyclone tapping observations as well as slag tap temperature. Secondary air was increased from a nominal 800°F to 900°F. Slag tap temperature did not change appreciably but visual observations showed improvement on slag tapping on the cyclone and bottom tap. It should be mentioned that the pilot facility requires higher secondary air (about 100°F) than full-scale units to achieve acceptable slagging performance.

Sludge Moisture Content – As explained earlier these tests were performed with a second batch of sludge that was different from the remainder of the tests. A second batch of sewage sludge was dried to 2% and 10% moisture. We repeated the previous results with 2% moisture sludge with coal at a nominal 70-75% sludge heat input. The cyclone was hot and slag was tapping. Similar to the previous test, when we staged the cyclone, slag tapping continued but a few more particles left the cyclone and entered into the primary furnace. Short-term (one to two hours) tests showed that 10% moisture sludge performed similarly to 2% moisture sludge (slag tapping did not change). This was the most notable result of these tests. After about two days of testing various parameters, some slag deposits in front of the scroll burner began to form, and this negatively impacted the combustion performance. The higher moisture content of sludge and coal and less uniform fuel feed could have contributed to development of slag deposits in cyclone.

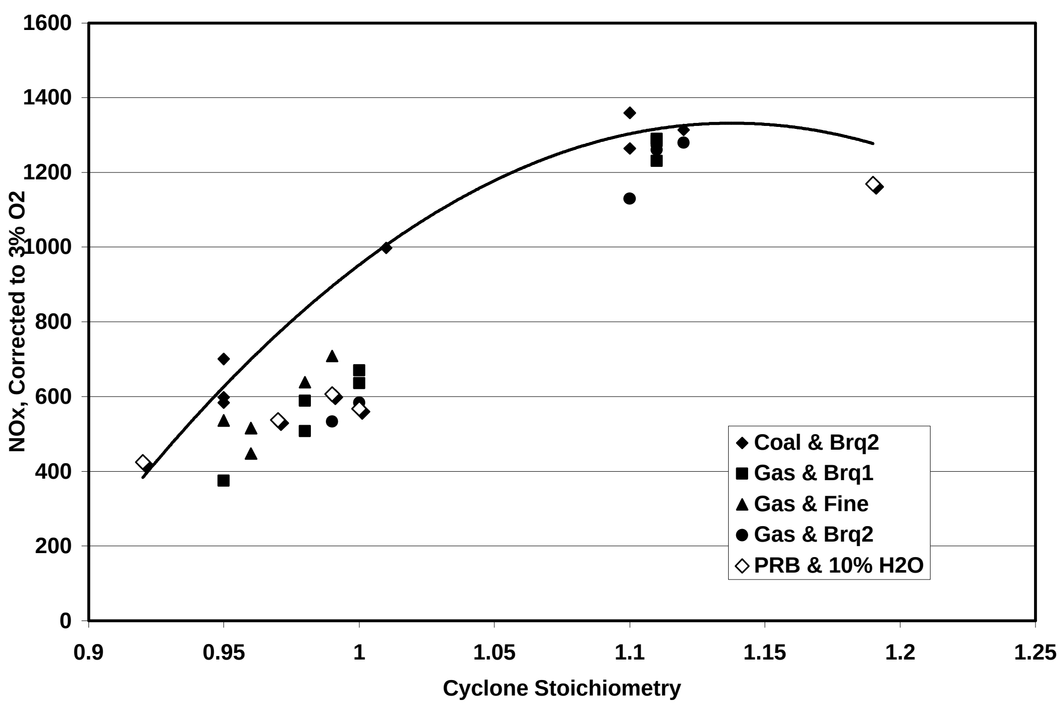

Figure 3-7. Effect of Sludge Moisture Content on Combustion and NO_x Levels

Environmental Measurements – The purpose of these measurements was to determine the selected gaseous and solid emission levels from the combustion of sewage sludge. These data will be utilized to determine if any emission reduction technique is required. The target environmental specifications were as follows:

NO_x	< 0.3 lb/MBtu
SO_2	< 0.7 lb/MBtu
CO	<150 ppm
VOC	< 0.05 lb/MBtu
Particulates	< 0.02 lb/MBtu
Mercury	< $50x10^{-6}$ gram/dscm

NO_x, CO, SO_2, VOC, and mercury emissions were measured during these tests. Continuous measurement of NO_x, CO, SO_2 was performed during all tests (see Table 1). VOC and mercury measurements were performed at the optimum conditions.

NO_x Emissions – As discussed before, NO_x emissions were measured under the uncontrolled and staged firing conditions. Figure 3-8 illustrates the uncontrolled NO_x emissions for sewage co-firing with coal and natural gas. For coal co-firing the NO_x emissions increased from 690 ppm to a maximum of 360 ppm when sewage sludge heat input varied between zero (coal firing only) and to 62.1%. As the sludge heat input increased to 74.5%, the NO_x emissions decreased slightly to 1314 ppm. Increasing the sludge heat input to 85% produced an unacceptable firing condition, and the NO_x emissions reduced further. With natural gas co-firing the NO_x emissions increased from 305 ppm to a maximum of 1281 ppm when sludge heat input varied between zero (natural gas firing) to 72.9%. Increasing the sludge heat input to 81%, NO_x emissions decreased slightly to 1130 ppm.

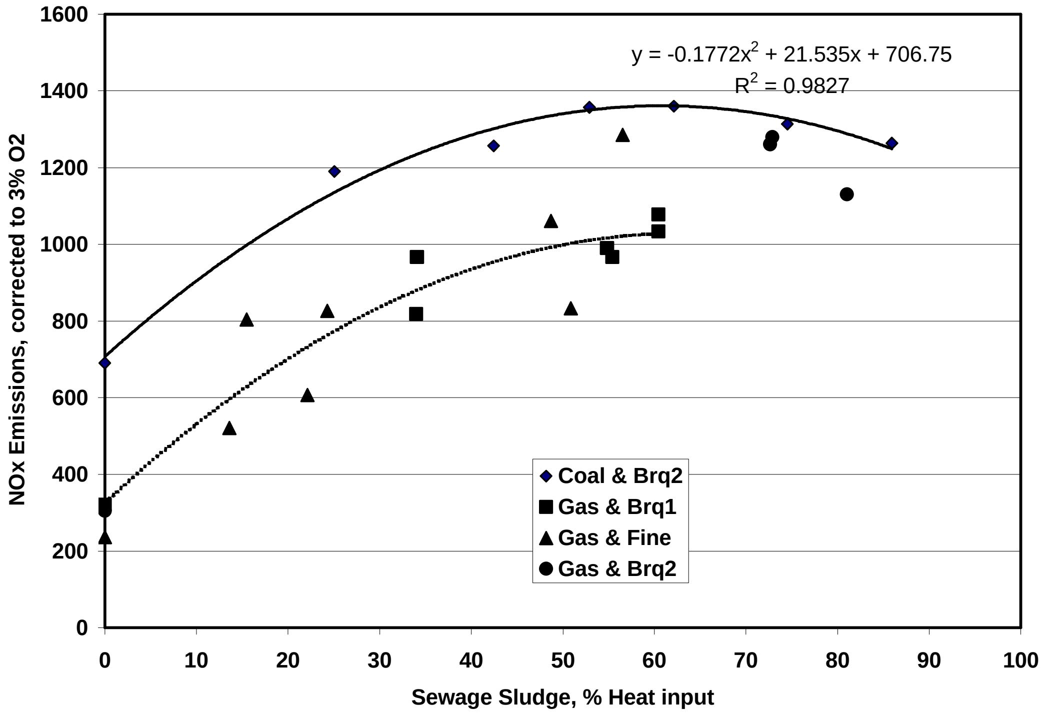

Figure 3-8. Uncontrolled NO_x Emissions for Sewage Co-firing with Coal and Natural Gas

Figure 3-9 illustrates the staged NO_x emissions for all tests with a sludge heat input of above 60%. For coal co-firing the NO_x emissions decreased from 1360 ppm to 584 ppm when cyclone stoichiometry varied between 1.12 to 0.95. With natural gas co-firing the NO_x emissions decreased from 1281 ppm to 375 ppm when cyclone stoichiometry varied between 1.11 to 0.95. Lower NO_x emissions could be achievable (by reducing the cyclone stoichiometry) but it could adversely affect the sludge throughput.

Since this NO_x level is higher than the target value of 0.3 lb/MBtu, a NO_x reduction process is required to control the NO_x levels. SCR or SNCR technology could be employed to reduce the NO_x emissions. Also, reburning technology is a combustion modification technique that technically shows promise for this application.

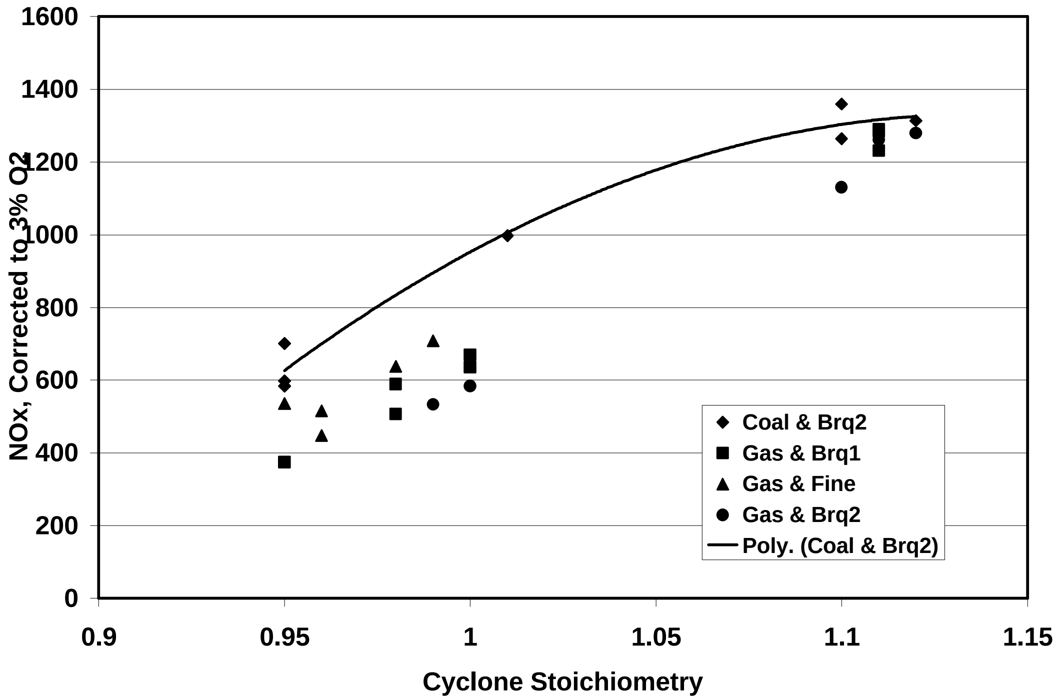

Figure 3-9. Staged NOx Emissions for Sewage Sludge Co-firing

SO_2 Emissions – Calculated SO_2 emissions from the sewage sludge analysis indicate that the maximum SO_2 emissions (100% sewage sludge firing) is 1.96 lb/MBtu. Firing the sewage sludge with natural gas and coal produced 1144 ppm and 1330 ppm SO_2 for natural gas and coal firing in the SBS with 81% and 75% sludge heat input, respectively. The technology would need a scrubber for reducing the SO_2 emissions.

VOC Emissions – VOC measurements were made during the optimum conditions with natural gas and coal co-firing. Detailed analysis was performed on two gas samples with GCMS. The coal/sewage sludge firing produced no VOC (or below the 0.5 ppm detection limit). Natural gas/sewage sludge only produced 0.5 ppm of VOC. The VOC concentrations from commercial cyclone and pulverized coal boilers are in the range of 1 to 2 ppm. Therefore, VOC from co-firing of sewage sludge and coal or natural gas in a cyclone boiler does not present a problem.

Mercury Emissions – Mercury is a regulated heavy metal. Mercury is found in the combustion gas in both the elemental and oxidized conditions. A scrubber can remove oxidized mercury more easily than elemental mercury. Therefore, mercury emission measurements were performed during optimum conditions to determine the emission levels as well as mercury speciation. Triplicate mercury measurements were performed at the convection pass exit by the Ontario-Hydro Method. The mercury concentrations were 144×10^{-6} grams/ Nm^3. This concentration was expected because the mercury concentration in the sludge was 1.0 ppm. A high percentage (76.7%) of mercury was oxidized which was attributed to a chlorine level of 0.21% in the sludge. Since a high percentage of mercury is in oxidized form a scrubber should be able to reduce the mercury concentrations to 50×10^{-6} grams/Nm^3.

3.4 WBS Level 3 Task I.4: Economic Evaluation

Objectives

In response to DOE's "Solids Fuels and Feed Stocks Grand Challenges Program", Minergy Corporation as a sub-contractor to McDermott Technology, Inc. (MTI) has performed an economic evaluation originally quoted as Task I.4. The intent and objective of this evaluation is to determine if a new solid fuel, developed from a mixture of coal and biomass wastes can be produced and converted efficiently and effectively into electric power to provide an adequate return on the capital invested in the project.

Project Description

For the purposes of an economic study Minergy Corporation has assumed that the project consists of a new power plant which would take the new solid fuel and convert it into electricity to be sold to the grid. The project would be a new Greenfield power plant versus a retrofit of an older existing facility. The economic analysis assumes that both the coal and the biomass wastes are procured separately but directly from the suppliers. It also assumed that municipal biosolids, a by-product of the operation of municipal wastewater treatment facilities, is the source of the biomass waste. This material has a higher heating value equivalent to that of many western coals and has acceptable melting characteristics. The latter characteristic is important for operating in a cyclone so that the residual inorganic fraction is melted into a vitreous glass product. It is assumed that the biomass is already dried and prepared for combustion prior to delivery to the facility.

Process Description

The coal and biomass mixture would be combusted in a B&W style cyclone boiler. This process converts the fuel value in the coal and biomass into heat, which is then used to generate steam to produce power in the traditional rankine cycle.

The process also consists of all technically proven equipment such as steam turbines and power boilers.

Air quality control equipment also assumes that demonstrated technologies will be used. NO_x control is accomplished using a combination of over fire air and urea/ammonia injection. Sulfur control is achieved via a dry scrubber. Particulate control is provided by a fabric filter.

Project Benefits

A number of benefits are associated with the commercialization of this technology:

- **Furthers the Goals of Environmental Protection –** Sludge is derived as a byproduct from wastewater treatment plants, which have been constructed to protect the country’s water resources. Thousands of tons of sludge are produced daily in wastewater treatment plants. This project will create two usable products from that sludge: glass aggregate and steam/power.

- **Creates an Inert and Marketable Product –** The inorganic fraction of the biomass is melted into an inert vitreous glass, which can be sold into the construction product marketplace. As a result, the system converts the waste product into fuel, then into a marketable product.

- **Reduction in Land Disposal –** Sludge has been historically disposed of in landfills or by land application. These disposal practices are under increasing scrutiny by environmental regulators and by the general public. Operation of this system will delay the need for new landfills.

- **Uses Renewable Resource as Fuel –** Sludge contains a very significant energy content which is considered a non-fossil fuel supply of energy. As state and federal lawmakers proceed to restructure the regulations that govern the electric utility industry, mandates have been issued requiring the utilities to secure significant non-fossil generation sources. There is a significant shortage of such projects, resulting in a significant pricing premium that such generation can command.

- **Reduces Truck Traffic –** Sludge trucking is an undesirable element in the disposal of sludge. Because it is wet and has odors associated with it, sludge can be difficult to transport long distances to landfills. By the utilization of a system as contemplated in this study, a significant reduction in the amount of sludge trucking can be realized. This will also result in the associated reduction in traffic congestion and diesel exhaust.

- **Uses Environmentally Friendly Technology –** State-of-the-art air quality control equipment would be installed to clean air emissions. The equipment will be continuously monitored.

- **Supported by Environmental Regulators –** State regulators put significant resources into the securing of alternative beneficial re-use of wastes such as sludge.

Economic Assumptions

Table 3.6 below is a summary of all performance and cost assumptions used in this analysis. This assumes that the installed capacity of the Power Plant is 25.0 MW, with a net output of 23.0 MW.

Table 3.6. Input Assumptions

Plant gross generator capacity	25.0	MW
Plant net power output	23.0	MW
Capital cost factor	1600	$/kW
Plant capital cost	$ 40,000,000	
Plant heat rate	12500	Btu/kWHr
Total heat input	313	mmBtu/Hr
Heat from coal	50%	Prct
Annual availability	90%	Prct
Annual full load hours	7884	Hrs/Yr
Price of coal (delivered)	1.75	$/mmBtu
Annual coal costs	$ 2,155,781	$/Yr
As fired heating value of municipal sludge	7500	Btu/Lb
Annual amount of municipal sludge processed	82125	Tons
Processing fee for municipal sludge	$ 22.00	$/Ton
Processing revenue	$ 1,806,750	$/Yr
Revenue for conventional energy	$ 0.05	$/kWHr
Revenue for renewable energy	$ 0.10	$/kWHr
Weighted average energy revenue	$ 0.075	$/kWHr
Annual electric revenue	$13,599,900	$/Yr
Annual glass aggregate production	$ 20,000	Tons
Revenue from product sales	$ 50.00	$/ton
Annual product revenue	$ 1,000,000	$/Yr
Annual non fuel O&M costs	$ 4,000,000	$/Yr

The assumed capital construction cost has been assumed at $1600 per kilowatt resulting in a $40 million total construction cost. A plant heat rate of 12,500 Btu per kilowatt-hour has been assumed along with a total heat input of 313 million Btu per hour. Based on the results of this testing it is felt this a very conservative estimate. 50% of the heat input is from coal, with the remaining 50% heat input from the biomass. The gross calorific value of the municipal sludge has been assumed at 7,500 Btu per pound. In order to obtain an energy balance on heat input the required input from biosolids would be 82,125 tons per year. It has been assumed that a processing fee would be collected for the dry biosolids of $22.00 per ton. The energy sold has been split into two components. The first component would be the portion or fraction of energy sold from conventional coal-fired generation. This has been assumed at a market rate of 5¢ per kilowatt-hour. The second component would be an energy premium for the biomass, since the biomass can be considered renewable. A renewable electrical sale price of 10¢ per kilowatt-hour has been assumed. This results in a weighted average energy revenue of 7½¢ per kilowatt-hour. The facility would also produce 20,000 tons per year of glass aggregate that could be sold at a rate of $50 per ton.

Economic Model

A project proforma has been developed for this study. The model assumes the project is developed using traditional project finance structure. In this manner, the project is capitalized with a combination of bank financing and equity from investors. The model incorporates values for bank debt cost rate, the amount of investor equity invested, taxes, construction interest, project soft costs, depreciation, and tax life, and inflation. A summary of the economic assumptions is shown on Table 3-7 below.

Table 3-7. Finance Assumptions

Project Type	Project Finance
Interest on bank debt	8%
Amount of back finance	65%
Investor Equity	35%
Gross receipt tax	3%
Total state and federal income tax	40%
Construction interest costs	$ 2,000,000
Project soft costs	$ 3,500,000
Debt term	20 Years
Amortization term	30 Years
Tax life	20 Years
Tax depreciation schedule	MACRS
Inflation	3%

Economic Results

The economic model was built using the input assumptions in Table 3-6 as well as the finance assumptions shown in Table 3-7. The results from this have been called the "base case". Table 3-8 is a summary result of return on equity for both base cases and several other sensitivity cases.

The purpose of the sensitivity cases is to determine where most of the project risks lie. As mentioned, the base case results in an internal rate of return on equity (IRR) of 24% (at year ten) with an average net income of $4 million per year averaged over the first ten years of the project.

Table 3-8. Economic Model Outputs

Case	Base	Case 1	Case 2	Case 3	Case 4
Return on Equity	24%	27%	27%	22%	31%
Average net income (x1000)	$ 4,023	$ 4,509	$ 4,496	$ 3,663	$ 5,328

Case 1 Reduce co-fire ratio from 50% coal to 45% coal
Case 2 Increase processing fee from $22.00/ton to $30.00/ton
Case 3 Product revenue from $50/ton to $25/ton
Case 4 Increase weighted average energy revenue rate from $0.075/kWHr to $0.10/kWHr

The first sensitivity case is co-fire ratio in which the amount of coal burned is reduced from 50% of total heat input to 45% total heat input. This raises the IRR by 3% and the average net income by approximately $500,000 per year. The second sensitivity case changes the biomass processing fee rate of $22 per ton to $30 per ton. This results in nearly identical economic performance as improving the co-coal fire rate. The third sensitivity case reduces the product revenue for the glass aggregate from $50 a ton to $25 per ton. This results in a 2-percentage point drop in IRR and approximately $300,000 reduction in average net income. The fourth and final case changes the weighted average energy component from 7½¢ per kilowatt-hour to 10¢ per kilowatt-hour. This improves the IRR by 7-percentage points and increases the average net income to $5.3 million per year.

4.0 CONCLUSIONS AND RECOMMENDATIONS

1. SDF can be produced by partially drying and pelletizing sewage sludge.

2. Sewage sludge, when properly dried and sized, can be successfully co-fired with natural gas and coal in a B&W cyclone boiler.

3. Finer particle size distributions, similar to the standard B&W size distribution for sub-bituminous coal, showed the best combustion and slagging performance.

4. Short-term (one to two hours) tests showed that sludge dried to10% moisture performed similarly to sludge dried to 2% moisture (slag tapping did not change).

5. Up to 74.6% and 78.9% sludge were successfully co-fired with pulverized coal and with natural gas, respectively.

6. Increasing the secondary air temperature from 800 F to 900 F improved slag tapping (judging by visual observation).

7. NO_x emission levels decreased, as expected, with cyclone stoichiometry. The uncontrolled NO_x emissions at the maximum sludge input were 1300 - 1400 ppm. NO_x emissions decreased to 460 - 625 ppm at a cyclone stoichiometry of 0.95 - 0.99. SCR or SNCR can be used to reduce NO_x emissions to the compliance level.

8. Firing the sewage sludge produced 1087 ppm and 1320 ppm SO_2 emissions for natural gas and coal firing with 78.9% and 74.6% sludge heat input, respectively. The technology would need a scrubber for reducing the SO_2 emissions.

9. VOC and CO emissions were very low (less than 0.5 ppm and less than 50 ppm, respectively) during the optimum conditions of coal and sludge co-firing. CO emissions were very sensitive to sludge feed rate fluctuations.

10. The mercury concentration in the stack was high (144x10^{-6} grams/ Nm^3) due to the high mercury concentration of the sludge (1.0 ppm). However, a high percentage (76.7%) of mercury was oxidized which was attributed to a chlorine level of 0.21% in the sludge. A scrubber should be able to reduce the mercury stack emission concentrations.

11. Based on the assumptions used, return on equities ranged from 22% to 31%. Major sensitivities are coal co-fire rates, processing fees for the biomass material, and electricity sales price. The return on equity should be adequate to attract investors and allow the project to proceed.

12. Significant variability exists between the sludge fuel properties from a given wastewater plant (seasonal and/or day-to-day changes) or from different wastewater plants. This is an important boiler design consideration and suggests that site-specific laboratory and bench-scale testing must be performed in order to determine its potential for firing in a cyclone boiler.

13. Additional market research and engineering will be required to verify the economic assumptions to the degree required by investors. Areas to focus on are:

    - Plant detail design and detail capital cost estimates.
    - Market research into possible project locations and biosolids availability at the proposed project locations.
    - Market research into electric energy sales and renewable energy sales opportunities at the proposed project location.

5.0 REFERENCES

1. "In Waste Water, the Talk is About Toxics", Chemical Week, October 12, 1977.

2. Minergy Internal Marketing Study.

APPENDIX A

Coal and Sludge Analyses

ACCREDITED

GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
(814) 886-7400
STANDARD LABORATORIES, INC.

DATE: 5-31-2000
SAMPLE NO. 640845

MCDERMOTT TECHNOLOGY, INC.
1562 BEESON ST.
ALLIANCE, OH 44601

SAMPLE ID: PRB COAL AS FIED

OPERATING CO.: P. O. 80561
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED: 5/12/00
DATE RECEIVED: 5/17/00
WEATHER:
GROSS WEIGHT:

OTHER ID: DOE/MINERGY TEST

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	20.95%	XXX
VOLATILE MATTER		34.25%	43.32%
FIXED CARBON	D3172	39.03%	49.38%
ASH	D3174	5.77%	7.30%
SULFUR	D4239 METHOD 3.3	.33%	.42%
CARBON	D3178	55.89%	70.70%
HYDROGEN	D3178	4.45%	5.63%
NITROGEN	D3179	.80%	1.01%
OXYGEN	D3176	11.81%	14.94%
BTU/LB	D2015 D1989	9503	12021
MAF BTU/LB			12968

LBS OF SO2 PER MILLION BTU .70

LBS OF SULFUR PER MILLION BTU .347

ASH MINERAL COMPOSITION
D2795 D3682

SILICON DIOXIDE	34.05 %
ALUMINIUM OXIDE	10.77 %
FERRIC OXIDE	4.46 %
TITANIUM DIOXIDE	1.59 %
PHOSPHORUS PENTOXIDE	1.12 %
CALCIUM OXIDE	22.52 %
MAGNESIUM OXIDE	3.25 %
SODIUM OXIDE	1.71 %
POTASSIUM OXIDE	.83 %
SULFUR TRIOXIDE	19.88 %

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APPROVED BY ______

PAGE 1 OF 1
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BLACK SEAL ANALYSIS

COMMERCIAL TESTING & ENGINEERING CO.
GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 630-953-9300 FAX: 630-953-9306
SINCE 1908
SGS Member of the SGS Group (Société Générale de Surveillance)
Committed To Excellence
ADDRESS ALL CORRESPONDENCE TO:
16130 VAN DRUNEN RD.
SOUTH HOLLAND, IL 60473
TEL: (708) 331-2900
FAX: (708) 333-3060

March 16, 2000

WISCONSIN ELECTRIC POWER CO.
Lab Services - A070
333 West Everett Street
Milwaukee, WI 53203
Attn: Dave Kollakowsky

Sample identification by
Wisconsin Electric Power Co.

Kind of sample reported to us: Coal

Sample ID: AB82563

Sample taken at: Wisconsin Electric Power Co.

Sample taken by: Wisconsin Electric Power Co.

Date sampled:

Date received: March 13, 2000

P.O. No. 4599999999

Analysis Report No. 71-115624-AD

Page 1 of 1

MINERAL ANALYSIS	Ignited Basis, % Weight
Silica, SiO_2	45.54
Alumina, Al_2O_3	22.79
Titania, TiO_2	1.04
Iron oxide, Fe_2O_3	14.23
Calcium oxide, CaO	5.98
Magnesium oxide, MgO	1.28
Potassium oxide, K_2O	1.07
Sodium oxide, Na_2O	1.28
Sulfur trioxide, SO_3	5.15
Phosphorus pentoxide, P_2O_5	0.49
Strontium oxide, SrO	0.17
Barium oxide, BaO	0.24
Manganese oxide, Mn_3O_4	0.04
Undetermined	0.70
	100.00

Silica Value = 67.94
Base:Acid Ratio = 0.34
T_{250} Temperature = 2495 °F

Type of Ash = BITUMINOUS
Fouling Index = 0.44

METHOD
Phosphorus pentoxide: ASTM D 2795; Sulfur trioxide: ASTM D 5016; Barium & Strontium oxide: ASTM D 3682-ICP
Balance of oxides: ASTM D 3682; Calculated Values per ASME

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.
Joseph B. Houser
South Holland Laboratory

MEMBER ACIL

03/13/2000 11:59 814-886-5526 STANDARD LABS INC PAGE 02

GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
(814) 886-7400
STANDARD LABORATORIES, INC.

DATE: 3-11-2000
SAMPLE NO. 629511

BABCOCK & WILCOX - BARBERTON
20 SOUTH VAN BUREN AVE.
BARBERTON, OH 44203

SAMPLE ID: SAMPLE F-6249 FINE SLUDGE COMPOSITE

OPERATING CO. :
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED: 2/28/00 DATE RECEIVED: 2/29/00
WEATHER:
GROSS WEIGHT:

OTHER ID: REF M180 1902 85 SE MINERGY (DETROIT PROJECT) SEWAGE SLUDGE ANALYSIS

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	3.00%	XXX
VOLATILE MATTER		59.17%	61.00%
FIXED CARBON	D3172	3.24%	3.34%
ASH	D3174	34.59%	35.66%
SULFUR	D4239 METHOD 3.3	.97%	1.00%
CARBON	D3178	39.48%	40.71%
HYDROGEN	D3178	6.04%	6.23%
NITROGEN	D3179	2.89%	2.98%
OXYGEN	D3176	13.03%	13.43%
BTU/LB	D2015 D1989	8079	8329
MAF BTU/LB			12945
LBS OF SO2 PER MILLION BTU			2.40
LBS OF SULFUR PER MILLION BTU		1.201	

ASH FUSION TEMPERATURE(S)

D1857	REDUCING ATMOSPHERE
INITIAL DEFORMATION TEMPERATURE	1980
SOFTENING TEMPERATURE	2040
HEMISPHERICAL TEMPERATURE	2100
FLUID TEMPERATURE	2150

D1857	OXIDIZING ATMOSPHERE
INITIAL DEFORMATION TEMPERATURE	2120
SOFTENING TEMPERATURE	2170
HEMISPHERICAL TEMPERATURE	2210
FLUID TEMPERATURE	2235

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BLACK SEAL ANALYSIS

03/13/2000 11:59 814-886-5526 STANDARD LABS INC PAGE 03

STANDARD LABORATORIES, INC.

DATE: 3-11-2000
SAMPLE NO. 6295[illegible]

CERTIFICATE OF ANALYSIS (CONT.)

ASH MINERAL COMPOSITION D2795 D3682	AS RECEIVED	DRY BASIS
SILICON DIOXIDE	39.41 %	
ALUMINIUM OXIDE	13.23 %	
FERRIC OXIDE	14.61 %	
TITANIUM DIOXIDE	1.73 %	
PHOSPHORUS PENTOXIDE	13.22 %	
CALCIUM OXIDE	9.07 %	
MAGNESIUM OXIDE	3.10 %	
SODIUM OXIDE	.85 %	
POTASSIUM OXIDE	2.31 %	
SULFUR TRIOXIDE	3.07 %	

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BLACK SEAL ANALYSIS

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GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
(814) 886-7400
STANDARD LABORATORIES, INC.

DATE: 3-11-2000
SAMPLE NO. 629512

BABCOCK & WILCOX - BARBERTON
20 SOUTH VAN BUREN AVE.
BARBERTON, OH 44203

SAMPLE ID: SAMPLE F-6250 (DAVENPORT)

OPERATING CO.:
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED: 2/28/00 DATE RECEIVED: 2/29/00
WEATHER:
GROSS WEIGHT:

OTHER ID: REF M180 1902 85 SE MINERGY (DETROIT PROJECT) SEWAGE SLUDGE ANALYSIS

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	6.27%	XXX
VOLATILE MATTER		62.29%	66.46%
FIXED CARBON	D3172	5.26%	5.61%
ASH	D3174	26.18%	27.93%
SULFUR	D4239 METHOD 3.3	.91%	.97%
CARBON	D3178	39.18%	41.80%
HYDROGEN	D3178	5.82%	6.21%
NITROGEN	D3179	3.68%	3.92%
OXYGEN	D3176	17.96%	19.17%
BTU/LB	D2015 D1989	7686	8200
MAF BTU/LB			11379
LBS OF SO2 PER MILLION BTU			2.36
LBS OF SULFUR PER MILLION BTU		1.184	

ASH FUSION TEMPERATURE(S)

D1857	REDUCING ATMOSPHERE
INITIAL DEFORMATION TEMPERATURE	1870
SOFTENING TEMPERATURE	1940
HEMISPHERICAL TEMPERATURE	2010
FLUID TEMPERATURE	2080
D1857	**OXIDIZING ATMOSPHERE**
INITIAL DEFORMATION TEMPERATURE	2150
SOFTENING TEMPERATURE	2210
HEMISPHERICAL TEMPERATURE	2240
FLUID TEMPERATURE	2275

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BLACK SEAL ANALYSIS

03/13/2000 11:59 814-886-5526 STANDARD LABS INC PAGE 05

STANDARD LABORATORIES, INC.

DATE: 3-11-2000
SAMPLE NO. 62951

CERTIFICATE OF ANALYSIS (CONT.)

ASH MINERAL COMPOSITION
D2795 D3682

	AS RECEIVED	DRY BASIS
SILICON DIOXIDE	32.83 %	
ALUMINIUM OXIDE	10.95 %	
FERRIC OXIDE	19.24 %	
TITANIUM DIOXIDE	1.73 %	
PHOSPHORUS PENTOXIDE	15.30 %	
CALCIUM OXIDE	9.97 %	
MAGNESIUM OXIDE	3.03 %	
SODIUM OXIDE	.95 %	
POTASSIUM OXIDE	2.61 %	
SULFUR TRIOXIDE	3.99 %	

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BLACK SEAL ANALYSIS

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GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
(814) 886-7400
STANDARD LABORATORIES, INC.

DATE: 3-11-2000
SAMPLE NO. 629513

BABCOCK & WILCOX - BARBERTON
20 SOUTH VAN BUREN AVE.
BARBERTON, OH 44203

SAMPLE ID: SAMPLE F-6252 (BRIQUETTED SLUDGE #2)

OPERATING CO.:
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED: 2/28/00 DATE RECEIVED: 2/29/00
WEATHER:
GROSS WEIGHT:

OTHER ID: REF M180 1902 85 SE MINERGY (DETROIT PROJECT) SEWAGE SLUDGE ANALYSIS

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	3.69%	XXX
VOLATILE MATTER		57.93%	60.15%
FIXED CARBON	D3172	3.18%	3.30%
ASH	D3174	35.20%	36.55%
SULFUR	D4239 METHOD 3.3	.95%	.98%
CARBON	D3178	37.94%	39.39%
HYDROGEN	D3178	5.95%	6.17%
NITROGEN	D3179	2.79%	2.90%
OXYGEN	D3176	13.48%	14.00%
BTU/LB	D2015 D1989	8001	8308
MAF BTU/LB			13095
LBS OF SO2 PER MILLION BTU			2.36
LBS OF SULFUR PER MILLION BTU		1.187	

ASH MINERAL COMPOSITION
D2795 D3682

SILICON DIOXIDE	37.12 %
ALUMINIUM OXIDE	13.13 %
FERRIC OXIDE	19.12 %
TITANIUM DIOXIDE	1.77 %
PHOSPHORUS PENTOXIDE	12.50 %
CALCIUM OXIDE	9.01 %
MAGNESIUM OXIDE	2.90 %
SODIUM OXIDE	.81 %
POTASSIUM OXIDE	2.30 %
SULFUR TRIOXIDE	2.94 %

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PAGE 1 OF 1
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BLACK SEAL ANALYSIS

ACCREDITED

GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
(814) 886-7400
STANDARD LABORATORIES, INC.

DATE: 5-31-2000
SAMPLE NO 640844

MCDERMOTT TECHNOLOGY, INC.
1562 BEESON ST.
ALLIANCE, OH 44601

SAMPLE ID: SEWAGE SLUDGE

OPERATING CO.: P. O. 80561
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED: 5/10/00
DATE RECEIVED: 5/17/00
WEATHER:
GROSS WEIGHT:

OTHER ID: SEWAGE DRIED & ADDED WATER

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	10.46%	XXX
VOLATILE MATTER		49.86%	55.69%
FIXED CARBON	D3172	5.93%	6.62%
ASH	D3174	33.75%	37.69%
SULFUR	D4239 METHOD 3.3	.60%	.67%
CARBON	D3178	32.38%	36.16%
HYDROGEN	D3178	4.58%	5.11%
NITROGEN	D3179	2.65%	2.96%
OXYGEN	D3176	15.58%	17.40%
BTU/LB	D2015 D1989	7402	8267
MAF BTU/LB			13268
LBS OF SO2 PER MILLION BTU			1.62
LBS OF SULFUR PER MILLION BTU		811	

ASH MINERAL COMPOSITION
D2795 D3682

SILICON DIOXIDE	34.98 %
ALUMINIUM OXIDE	10.63 %
FERRIC OXIDE	13.94 %
TITANIUM DIOXIDE	1.31 %
PHOSPHORUS PENTOXIDE	10.50 %
CALCIUM OXIDE	17.80 %
MAGNESIUM OXIDE	3.13 %
SODIUM OXIDE	1.22 %
POTASSIUM OXIDE	2.26 %
SULFUR TRIOXIDE	4.43 %

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PAGE 1 OF 1
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BLACK SEAL ANALYSIS

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GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
(814) 886-7400
STANDARD LABORATORIES, INC.

DATE: 5-31-2000
SAMPLE NO. 640843

MCDERMOTT TECHNOLOGY, INC.
1562 BEESON ST.
ALLIANCE, OH 44601

SAMPLE ID: SEWAGE SLUDGE

OPERATING CO.: P. O. 80561
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED: 5/12/00
DATE RECEIVED: 5/17/00
WEATHER:
GROSS WEIGHT:

OTHER ID: DRIED TO 10% MOISTURE DOE/MINERGY TEST

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	10.76%	XXX
VOLATILE MATTER		52.97%	59.37%
FIXED CARBON	D3172	4.68%	5.23%
ASH	D3174	31.59%	35.40%
SULFUR	D4239 METHOD 3.3	.57%	.64%
CARBON	D3178	33.36%	37.39%
HYDROGEN	D3178	4.79%	5.37%
NITROGEN	D3179	2.77%	3.10%
OXYGEN	D3176	16.16%	18.10%
BTU/LB	D2015 D1989	6510	7296
MAF BTU/LB			11294
LBS OF SO2 PER MILLION BTU			1.75
LBS OF SULFUR PER MILLION BTU		.876	

ASH MINERAL COMPOSITION
D2795 D3682

SILICON DIOXIDE	36.60 %
ALUMINIUM OXIDE	10.28 %
FERRIC OXIDE	14.28 %
TITANIUM DIOXIDE	1.24 %
PHOSPHORUS PENTOXIDE	10.30 %
CALCIUM OXIDE	17.07 %
MAGNESIUM OXIDE	3.16 %
SODIUM OXIDE	1.18 %
POTASSIUM OXIDE	2.23 %
SULFUR TRIOXIDE	4.00 %

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APPROVED BY ____

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BLACK SEAL ANALYSIS

APPENDIX B

Sewage Sludge Material Safety Data Sheet (MSDS)

02/11/1999 12:08 4142721738 MGJWMETPMPDWDPAGD PAGE 02

Milorganite

MATERIAL SAFETY DATA SHEET

MSDS Code: 001

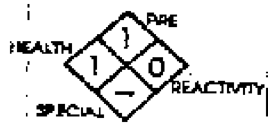
Address: 260 West Seeboth Street
Milwaukee, WI 53204

EMERGENCY ASSISTANCE

Monday through Friday
7 am-5 pm: 414-221-6810
Other Times: 414-482-2040

Date of Preparation: 01/01/96
Replaces: 01/02/93

NFPA Rating



HMIS Rating

HEALTH	1
FLAMMABILITY	1
REACTIVITY	0

Hazard Categories:
4 = Extreme 2 = Moderate
3 = High 1 = Slight
0 = Insignificant

SECTION 01 PRODUCT IDENTIFICATION

Trade Name: Milorganite®

Product Class: Natural Organic Fertilizer

SECTION 02 INGREDIENTS

Material	% By Weight
Organic solids from activated sewage sludge	95 - 97%
Water	Balance

Exposure Limits

	PEL	TLV
Total Dust	15 mg/M3	10 mg/M3
Respirable Fraction	5 mg/M3	--

Trace metals and volatile organics can be detected in the finished product in quantities less than [illegible] less than 0.1%.

PRECAUTIONARY STATEMENT FOR BULK STORAGE

May form explosive dust-air mixtures

SECTION 03 HEALTH EFFECTS INFORMATION

Primary Routes of Entry	Signs and Symptoms of Overexposure
Inhalation	May cause nasal and throat irritation
Eye Contact	May cause irritation
Skin Contact	May cause skin irritation
Skin Absorption	Skin absorption . . likely
Ingestion	Not an expected route of exposure during customary and reasonably foreseeable use.

Health Conditions Which May Be Aggravated By Exposure:

Individuals with respiratory ailments, such as asthma, may be particularly sensitive to dust exposure. Product may contain sensitizers in quantities below 1.0%.

Carcinogens:

This product may contain substances considered to be carcinogens by OSHA, IARC and NTP, but they would not be present in quantities greater than 0.1%.

FIRST AID AND EMERGENCY CARE

Eye Contact	Flush eyes with clean water continuously for at least 15 minutes. Remove contact lenses and lift eyelids while flushing Obtain medical attention if pain or redness persists after flushing is completed.
Skin Contact	Wash skin thoroughly with soap and water.
Inhalation	If breathing difficulty should occur, remove from the area to fresh air and obtain medical attention if symptoms of illness appear or if breathing difficulty continues.
Ingestion	Not an expected route of exposure. If ingestion occurs consult with a physician.

02/21/1999 12:08 4142721738 MGJWMDTPMPDWDPAGD PAGE 04

Milorganite®
Page 3 of 6
MSDS 001

SECTION 04 PHYSICAL AND CHEMICAL DATA

Appearance: Black, granular solid

Odor: Earthy

Solubility: Insoluble

Boiling Range: NA

Melting Point: NA

Evaporation Rate: NA

Vapor Pressure: NA

Vapor Density: NA

pH: NA

...ile: Negligible

Specific Gravity: Bulk Density 42 - 46 pounds/cubic foot

SECTION 05 FIRE AND EXPLOSION DATA

Fire: Combustible solid

Explosion: Dust dispersed in air in sufficient concentrations may create an explosion hazard in the presence of ignition sources.

Extinguishing Media: Water, dry chemical, foam

Special Firefighting Procedures: No special procedures. Full protective gear including self-contained breathing apparatus in positive pressure mode should be worn as in any fire fighting situation.

SECTION 06 REACTIVITY DATA

Stability: Stable under ordinary conditions of use and storage.

Incompatibilities: Strong oxidizing agents

Conditions to Avoid: Heat, sparks, open flames

Hazardous Decomposition Products: In the event of a fire, will produce carbon monoxide, carbon dioxide, oxides of nitrogen and other products of organic combustion.

Hazardous Polymerization: Will not occur.

SECTION 07 SPILL OR LEAK PROCEDURES

Spill Clean Up: Clean up all quantities.

Large Bulk Quantities: Remove or eliminate all sources of ignition. Material should be picked up in a manner that minimizes dispersion of dust into the air. Non-sparking equipment and tools should be used. Clean up personnel should wear respiratory protection against dust.

Waste Disposal: Material should be recovered and saved for use whenever possible. State and local requirements for waste disposal may be more restrictive or otherwise different from federal laws and regulations. Consult state and local regulations regarding proper disposal of this material.

SECTION 08 EXPOSURE CONTROL/PERSONAL PROTECTIVE EQUIPMENT

Engineering Controls: Efforts must be made to maintain dust levels below the exposure limits.

Bagged Quantities: General ventilation should be sufficient.

Bulk Quantities: Additional ventilation may be required. Air monitoring should be performed during typical work practices to determine average exposure levels. When these exceed the permissible limits, additional engineering controls must be implemented and respiratory protection is required.

Work Practice Controls: Good housekeeping procedures should be maintained to minimize dust accumulation on indoor surfaces. Good personal hygiene practices should be followed.

Workers should be advised to empty containers in a manner which minimizes their exposure, e.g., do not vigorously shake the bag as it is being emptied.

When emptying packages or containers outdoors, common sense should be used to empty the containers where wind conditions will not increase exposure.

Respiratory Protection: A NIOSH approved respirator equipped with a HEPA dust filter should be used whenever dust levels cause symptoms of irritation or sensitivity. Whenever respiratory protection is worn, a complete respiratory protection program should be implemented in accordance with OSHA General Industry Standard 29CFR1910.134.

Eye Protection: Safety glasses should be used to prevent dust exposure. Tight fitting goggles may be needed to ensure greater protection. Individuals with contact lenses may need to wear goggles to prevent dust irritation.

Skin Protection: Special equipment is not required. Clean body-covering clothing should be worn.

SECTION 09 SPECIAL STORAGE AND HANDLING PROCEDURES

Use according to label instructi...

Consult local fire codes or insurance carrier for information on storage of bulk quantities.

SECTION 10 ENVIRONMENTAL INFORMATION

This product is comprised of treated processed and stabilized biosolids and, as such, its composition is closely regulated by EPA under the Water Quality Act of 1987 and by state laws governing fertilizer components. Constituents must be closely monitored and strict limitations have been placed on the quantity of metals and other substances that may be found in the product.

When applied to land in accordance with the guidelines of accepted agronomic practices, there are no known adverse effects on plants, animals or aquatic life. Entry into surface water systems should be avoided since the nutrient content of this product will increase growth rates of affected plant populations.

SECTION 11 REGULATORY INFORMATION

OSHA Hazard Communication Standard 29CFR 1910.1200:
Considered nuisance dust. Product analysis identifies the average percentage (by weight) of individual metals and other contaminants to be less than 1.0%, most less than 0.1%.

Superfund Amendment and Reauthorization Act of 1986 (SARA):
Section 302, Section 313: May contain substances that are listed in Sections 302 and 313 but they would not be present in quantities greater than 1.0% and it is unlikely that product use would reach the reportable thresholds.

Section 311-312: Product is classified as a nuisance dust which, as an irritant, could be a potential acute and chronic health hazard.

Individual states may have specific requirements for worker or community right-to-know that differ from the federal requirements. If additional information is needed, call the number listed on page 1.

Toxic Substances Control Act (TSCA):

The chemical ingredients in this product are on the 8(b) Inventory List (40 CFR 710) in quantities less than 1.0%.

Resource Conservation and Recovery Act (RCRA), 40 CFR 261:

If this product becomes a waste, it does not meet the criteria of a hazardous waste.

SECTION 12 USER'S RESPONSIBILITY

This Material Safety Data Sheet provides safety and health information compiled from product analysis and standard toxicological and regulatory references. This product should be used in applications consistent with our product labeling.

Abbreviations:

EPA: Environmental Protection Agency
HEPA: High Efficiency Particulate Absolute
HMIS: Hazardous Materials Information System
IARC: International Agency for Research on Cancer
NA: Not Applicable
NFPA: National Fire Protection Association
NIOSH: National Institute of Occupational Safety and Health
NTP: National Toxicology Program
OSHA: Occupational Safety and Health Administration
PEL: Permissible Exposure Limit
TLV: Threshold Limit Value

APPENDIX C

Briquetting and Drying Processes

MIDLAND RESEARCH CENTER

A WHOLLY OWNED SUBSIDIARY OF MIDLAND STANDARD INCORPORATED
POST OFFICE BOX 67
NASHWAUK, MN 55769-0067
PHONE (218) 885-1951
FAX (218) 885-1955

February 1, 2000

Mr. Vladimir Ashtamenko, P.E.
Minergy Corporation
N 16 W 23217 Stone Ridge Drive
Suite 100
Waukesha, WI 53188-1155

Dear Vladimir;

As you requested in our last telephone conversation, I have written up a summary describing the equipment and flowsheet used to prepare the specified size agglomerate from sewer sludge dust.

We appreciate the prompt payment of our invoice. Please contact me if you have further need of the Midland Research Center facilities.

Sincerely,

Frank W. Kangas

Frank W. Kangas
Metallurgist

cc: R. R. Smith
File

DESCRIPTION OF SEWAGE AGGLOMERATION PLANT

The purpose of this small continuous pilot plant flowsheet was to agglomerate, in a specified range, 3 tons of fine dried sewage sludge. The sludge sample, as received at Midland Research Center, contained 2% moisture. As part of the agglomeration process, an additional 8% water addition was requested. This was not possible because the crushed briquettes at a 10% moisture level would contain a high percentage of flat, elongated oversize material upon screening. This material would have to be recycled through the roll crusher which would significantly lower the production rate of the desired size product. However, an additional 5% water addition level was achieved.

A total of 7,283 pounds (3.64 short tons) of crushed and screened briquette agglomerate was produced. The average structure of the product was 8.6% +4M, 86.8% +4M-30M, and 4.6% -30M.

The first piece of equipment in the flowsheet was a ribbon blender; this was replaced about one-fourth of the way through the production run with a double mixing compartment Muller mixer. Mixer replacement was necessary due to problems with the gear drive on the ribbon blender. Approximately 600 pounds of sludge and the 5% water addition were mixed as one batch. This mix was then fed by a conveyor belt to a Model 10.3-4MS Komarek-Greaves briquetting machine; the briquetting rolls had a 1/2 inch diameter pocket configuration. The strips of briquettes were then fed to a Denver roll crusher with the 8 inch diameter by 5 inch wide steel rolls set at a predetermined opening. The roll crusher product was fed by conveyor belt to a Midwestern 4 foot diameter double deck screener; the top deck screen had 4 mesh openings and the bottom deck had 30 mesh openings. The top deck oversize was recycled back to the briquetter. About one-third of the way through the run, the top deck oversize was recycled directly back to the roll crusher to increase product production rate due to time constraints. The –4 mesh+30 mesh product was put back into the original steel drums. the average weight of product in each drum was 303.5 pounds.

RESOURCE CHANGE, INC.

"Innovative Solutions To Environmental Challenges"

Post-it® Fax Note 7671	Date OCT 25 99 # of pages ▶
To HAMID FARZAN	From VLAD
Co./Dept. McDERMOTT Co.	Co. MINERGY
Phone # (330) 829-7385	Phone (414) 225-6163
Fax # (330) 829-7283	Fax # (414) 245-6166

Vlad Ashtamenko
Minergy Corporation
N16 W23217
Stone Ridge Drive Suite 100
Waukesha, WI. 53188-1155

Dear Vlad,

The de-watered sludge arrived at the Mount Holley MUA in (2) -40 yd. trucks with a plastic liner and covered with a tarp. The cake was then dumped into the storage area (a concrete pit with drains). The MHMUA workers removed remnants of the plastic liner by hand from the cake. The cake was then transported by front-end loader from the storage area up a ramp and dumped into a 20 cu. yd. storage hopper. The cake was then augured into the feed hopper and with a patented designed feed system, fed into the dryer. The cake then passed through 3 different heat zones, heated by burners on the outside of the rotating tube, and moved through the tube by a hollow flight screw auger, continuously churning the material for maximum exposure of the wet surfaces. This auger is filled with continuously pumped, food grade oil, which is heated by a separate hot oil unit.

Emissions from the dehydrator containing small amounts of contaminants in the exhaust vapors were condensed by lowering the air stream temperature below the dew point. The condensed water mixed with air was returned to the water treatment system.

Each step of the dehydration process was carefully monitored and adjusted through motor speed controls and temperature instrumentation on an hourly basis. The 42.63 tons of wet cake percentage of total solids ranged from 31.22% to 33.75%. The air lock temperature ranged from 110 degrees centigrade to 125 degrees centigrade with a residence time between 2.91 and 3.02 hrs. This process resulted in producing a dry product between 97.27 and 99.64% of total solids.

The product was augured into a chute, then through a cloth baffle (to minimize dust) and into eighty-three (83) 55 gal. drums. The drums were numbered and labeled accordingly. The drums were then loaded on pallets, (4 drums per pallet), secured for transportation and loaded by forklift into a box truck and forwarded to it's final destination.

Please call me if I can be of any additional assistance.

Sincerely,

Ernest Martinek, Pres.

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APPENDIX D

Sewage-Derived Fuel Firing Conditions and Results

Summary of Results												
Test	Sludge	Aux. Fuel	Sludge % Heat Input	Air Temp. °F	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Tap Temp. °F	Observations	Cyclone Stoich.	Date
Base001	Fine	Gas	0.0	806	0.75	265	16	70			1.03	8/17/99
Base002	Fine	Gas	13.6	825	1.3	570	16	150			1.06	8/18/99
Base003	Fine	Gas	22.1	835	2	640	16	255			1.09	8/18/99
Base004	Fine	Gas	15.5	818	4.2	750	14	250			1.22	8/19/99
Base005	Fine	Gas	48.7	808	2	1120	40	650			1.09	8/19/99
Base006	Fine	Gas	24.3	907	1.85	879	45	354		Better slag tapping	1.08	8/20/99
Base007	Fine	Gas	50.9	922	2	879	45				1.09	8/20/99
Base008	Fine	Gas	56.5	922	1.4	1400	30	850		CO up to 3000 ppm	1.06	8/20/99
BrqG001	Briq #1	Gas	0.0	818	0.7	361	350		2422		1.03	1/24/00
BrqG002	Briq #1	Gas	34.0	812	1.65	880	20	530	2220	Dirty glass lowers temp.	1.08	1/25/00
BrqG004	Briq #1	Gas	54.8	813	2	1045	23	840	2320		1.09	1/25/00
BrqG005	Briq #1	Gas	34.1	943	2	1020	17	520		No change in tapping	1.09	1/25/00
BrqG006	Briq #1	Gas	55.4	905	2	1020	17	520	2375		1.09	1/25/00
BrqG007	Briq #1	Gas	60.4	803	2.3	1120	17	915	2380		1.11	1/28/00
BrqG008	Briq #1	Gas	60.5	922	2.2	1080	16	775	2370	No change in tapping	1.11	1/28/00
BrqG009	Briq #1	Gas	60.3	877	2.15	590	15	805	2320		1.00	1/28/00
BrqG010	Briq #1	Gas	60.2	818	2.15	330	17	875	2300	Sludge going to bottom tap	0.95	1/28/00
BrqG011	Briq #1	Gas	59.8	933	2.35	265	17	875	2230	Barely tapping	0.90	1/28/00
BrqG012	Briq #1	Gas	59.8	951	2.35	1150	16	880	2422		1.11	1/28/00
DaveP001	D.Port	Gas	59.3	932	2.35	1150	16	880		Unacceptable carry over	1.11	1/28/00
DaveP002	D.Port	Gas	0.0	933	1.95	333	19	75	2455		1.09	2/7/00
DaveP003	D.Port	Gas	50.1	933	4	1150	23	650		Too much carry over	1.21	2/7/00
DaveP004	D.Port	Gas	0.0	933	2.5	282	16	68			1.12	2/8/00
DaveP006	D.Port	Gas	56.0	933	2	1150	19	910	2300	Screened, similar to briquetted	1.09	2/8/00
DaveP007	D.Port	Gas	53.7	843	2	500	35	880	2345	Tapping good, screened	0.97	2/8/00
Fine001	Fine	Gas	55.4	852	2.1	670	23	1140	2395	Tapping good	0.98	2/9/00
Fine002	Fine	Gas	64.7	852	2.1	670	23	1140		Tapping good	0.98	2/9/00
Fine003	Fine	Gas	74.9	886	2.2	740	23	1160	2440	Tapping good	0.99	2/9/00
HG001	Fine	Gas	68.22	811	2.2	560	19	950	2440	CO up to 300 ppm	0.95	2/9/00
HG002	Fine	Gas	61.29	810	2.5	460	30	890	2420	Tapping good	0.96	2/9/00
HG003	Fine	Gas	60.68	828	2.5	530	18	860	2480		0.96	2/9/00
Brq12	Briq #1	Gas	45.0	806	2	1139	16	652	2407	Tapping good	1.09	2/10/00
Brq13	Briq #1	Gas	59.1	824	2.6	1275	17	838	2530	Tapping good	1.13	2/10/00
Brq14	Briq #1	Gas	70.6	824	2.3	1340	17	950	2525	Tapping good	1.11	2/10/00
Brq15	Briq #1	Gas	70.7	824	2.2	530	23	960	2480	Tapping good	0.98	2/10/00

Summary of Results (Cont'd)												
Test	**Sludge**	**Aux. Fuel**	**Sludge % Heat Input**	**Air Temp. °F**	**O_2 %**	**NO_x ppm**	**CO ppm**	**SO_2 ppm**	**Tap Temp. °F**	**Observations**	**Cyclone Stoich.**	**Date**
Brq16	Briq #1	Gas	78.9	823	2.2	615	21	1087	2490	Tapping good	0.98	2/10/00
Brq17	Briq #1	Gas	87.9	825	2.6	650	19	1130	2530	Too much carry out to bottom tap	1.00	2/10/00
GasR001	Briq #2	Gas	0	831	2.75	309	13	70	2400		1.14	2/17/00
GasR002	Briq #2	Gas	72.9	801	2.5	1315	16	1047	2470	Tapping good	1.12	2/17/00
GasR003	Briq #2	Gas	81.0	835	2.2	1180	17	1144	2350	Too much carry out to bottom tap	1.10	2/17/00
GasR004	Briq #2	Gas	72.6	838	2.3	1310	17	1030	2445	Tapping good	1.11	2/17/00
GasR005	Briq #2	Gas	71.1	821	2.5	600	16	1020	2465		1.00	2/17/00
GasR006	Briq #2	Gas	70.1	817	2.3	554	16	945	2389	Tapping good	0.99	2/17/00
GasR007	Briq #2	Gas	71.2	928	2.5	750	18	1020	2470	Improved slagging	1.01	2/17/00
GasR008	Briq #2	Gas	71.2	938	2.5	1260	17	970	2414	Cooler than staged	1.12	2/17/00
Coal002	Briq #2	Coal	0.0	784	3	690	27	1220	2420	Cyclone is tapping	1.16	2/15/00
Coal003	Briq #2	Coal	25.1	824	3.3	1170	33	1130	2330	Cyclone is tapping	1.17	2/15/00
Coal004	Briq #2	Coal	42.5	823	2.1	1320	40	1295	2321	Cyclone is tapping	1.10	2/15/00
Coal005	Briq #2	Coal	52.9	823	2.3	1410	39	1223	2310	Cyclone is tapping	1.11	2/15/00
Coal006	Briq #2	Coal	62.1	824	2.2	1420	39	1295	2320	Cyclone is tapping	1.10	2/15/00
Coal007	Briq #2	Coal	74.5	848	2.5	1350	19	1330	2400	Cyclone is tapping	1.12	2/16/00
Coal008	Briq #2	Coal	85.9	848	2.2	1320	20	1370	2390	Too much carry over	1.10	2/16/00
Coal009	Briq #2	Coal	85.2	854	2.6	1020	20	1313	2413	Too much material going out	1.01	2/16/00
Coal010	Briq #2	Coal	85.7	854	2.5	720	40	1377	2360	Not satisfactory	0.95	2/16/00
Coal011	Briq #2	Coal	74.2	854	2.5	600	25	1320	2480	Cyclone is tapping	0.95	2/16/00
Coal012	Briq #2	Coal	74.6	854	2.2	625	21	1320		Cyclone is tapping	0.95	2/16/00
CoalM01	N/A	PRB	0	839	2.8	755	33	350	2250	Cyclone is tapping good	1.15	5/9/2000
CoalM02	Fine, 2%	PRB	68.0	833	2.76	1146	26	770	2220	Tapping good	1.14	5/9/2000
CoalM03	Fine, 2%	PRB	73.5	833	2.22	448	35-115	448	2360	More particle going to bottom	0.94	5/9/2000
CoalM04	Fine, 13%	PRB	71.5	833	3.4	555	37		2400	Cyclone tapping	1.00	5/9/2000
CoalM05	Fine, 13%	PRB	72.1	833	2.97	538	30	883	2360		0.97	5/9/2000
CoalM06	Fine, 13%	PRB	71.3	833	3.53	412	29		2300		0.92	5/9/2000
CoalM07	Fine, 13%	PRB	71.9	825	3.4	593	50		2286	SO_3 Measured	0.99	5/10/2000
CoalM08	Fine, 13%	PRB	71.5	855	3.67	1126	29	810	2469	Some particles going out	1.19	5/10/2000
GasM01	N/A	Gas	0	843	2.6	212	17	56	2350		1.13	5/8/2000
GasM03	N/A	Gas	0	843	3.9	200	12	60			1.21	5/10/2000
GasM04	N/A	Gas	0	1026	1.6	368	30				1.07	5/11/2000
GasM05	Fine, 6.7%	Gas	55.23	871	3	1050	30	575	2350	Cyclone is cold but tapping	1.15	5/11/2000